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THE SALT LAKE REGION

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THE SALT LAKE REGION

Prepared under the direction of

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THE SALT LAKE REGION

Prepared under the direction of John M. Boutwell

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By J. Cecil Alter

Salt Lake City is just south of the forty-first parallel of latitude about 2,100 miles (3,380 kilometers) west of New York, or about 2½ hours earlier by the sun. It is an over-the-Rockies neighbor to Denver, halfway between Omaha and San Francisco or Los Angeles, in the center of the western half of the United States.

Namesake of America's Dead Sea, the city spreads its artificial forest of ornamental trees on the upper talus of the Wasatch Mountains, from 4,250 to 4,850 feet (1,295 to 1,478 meters) above the ocean. It is about 15 miles (24 kilometers) from the southeast shore of Great Salt Lake, with a sterile, water-leveled plain intervening from the edge of the city, whence the lake has receded in centuries gone by. Southeastward from the city, and no farther distant than the lake, rise the Twin Peaks, 11,563 feet (3,525 meters) above sea level, two of many high points in this lofty range.

According to traditional history, the Great Salt Lake region was the borderland or neutral ground between the Shoshone Indians to the northwest, the Blackfoot tribes to the north, the Cheyennes to the northeast, the Comanches and Pawnees to the far southeast, the Apaches and Navajos to the south, and the Utes to the southwest. But the Rocky Mountains were formidable barriers to the more easterly tribes, and the desertlike regions to the south and west were deterrents to occupancy by the distant Indians in that direction. The Wasatch Mountains, trending longitudinally across the State from north to south, tended to sequester the Great Salt Lake region and to shield the Utes and Shoshones in the supremacy they were enjoying when found by the first white visitors and settlers.

Fur trappers and traders came into the Rocky Mountains in the early eighteen-twenties, spreading throughout the western mountains in search of beaver and other peltries.

It was in the early winter of 1824–25 that James Bridger, then a young fur trapper, descended the Bear River through the Wasatch Mountains and discovered Great Salt Lake. This region forthwith became the trappers' winter rendezvous for several years, both the Hudson's Bay Company from the northwest

and the American and Rocky Mountain Fur companies from the east foregathering in this region through the early eighteen-thirties.

On the heels of the trappers came John C. Frémont and other adventurers and explorers, who mapped and described the Great Salt Lake country in useful detail. With them came the vanguard of emigrants, in caravans and covered-wagon trains, gradually moving the American frontiers of civilization westward to the Pacific. These emigrant explorers followed the stream courses and the Indian trails to the Continental Divide, crossing the Rocky Mountains, chiefly through the South Pass, in what is now southern Wyoming, where the Continental Divide is lowest.

The emigrants of the eighteen-thirties and early eighteen-forties missed what is now Utah by a narrow margin, going well to the north of the Great Salt Lake, by way of the Portneuf and Snake Rivers, always halting for respites at Soda Springs ("Beer Springs") and Fort Hall, Idaho. Shortly a branch route led into California direct from the vicinity of Fort Hall down the Humboldt River; and later another route led diagonally across Utah to southern California, following the oldest route of all, the old Spanish Trail. The Overland stage route, immediate predecessor of the railroad, crossed mid-Utah to the Pacific for many years after the State was settled.

Scouting parties from emigrant trains looked wistfully upon the fertile oasis near the Great Salt Lake, with its heavy growth of sage brush, its luxuriant grasses, vines, flowers, and berry bushes growing from sweet, loamy soils; while Government and private explorers aided in advertising the region by their reports of its abundant water supply, genial climate, and picturesque and sheltered mountain setting; but all of the thousands kept their faces steadily toward the setting sun, bound for Oregon or California.

Thus the Utah region was still unoccupied, though fairly well known, when the Mormon people in 1847, then in difficulties in Missouri and Illinois, seized upon it as a colonizing sanctuary and moved here in large numbers the next 20 years or so. Large communities were literally transplanted bodily into the major Utah valleys. In a similar manner most of the outlying valleys of the State were subsequently settled by direction of the Mormon leader, Brigham Young.

The Mormon pioneers were just getting established in their mountain home when gold was discovered in California, loosing a flood of overland travel, mostly destined to be permanent settlers. But the Mormons entrenched themselves wisely and securely in this mid-continent location, by strict adherence to pastoral and agricultural pursuits, also devoting much time to

profitable barter and other business with the emigrants, worn and weary on the long overland journey. Many emigrants could go no farther than Utah and hence joined the Mormons in building their isolated commonwealth. The non-Mormon population increased rapidly from that time, and since the early eighteen-seventies it has practically equaled the Mormon population.

Originally the new commonwealth was called Great Basin, for it included practically the entire area known by that name; but when the time came to make more specific delineations of its boundaries, the area was curtailed, chiefly at the north and south, leaving the present Utah, Nevada, western Colorado, and southwestern Wyoming in the new territory, for which the Mormons proposed the name Deseret, a word taken from the Book of Mormon, signifying "industry" as symbolized by the honey bee. After several reductions in size, the present State of Utah was finally admitted to the Union in 1896.

Utah comprises 52,597,760 acres (21,285,646 hectares), of which 1,871,000 acres (757,000 hectares), or 3.6 per cent, is in cultivated crops. Because of the comparatively scanty precipitation and other fresh-water supplies, it has been estimated by the Utah Agricultural Experiment Station that no more than 2,500,000 acres (1,012,000 hectares), or about 5 per cent, can ever be farmed successfully in any manner. About 500,000 acres (202,000 hectares) of the land now farmed is tilled without irrigation. On this so-called dry-farm land crops are usually obtained only every alternate year, by careful tillage methods, which conserve the moisture of two seasons for one crop yield. About 44,000,000 acres (17,800,000 hectares), or 83 per cent of the State, is grazing land, about 5,000,000 acres (2,000,000 hectares) of which is timbered and contains about 5,000,000,000 board feet of lumber (equal to 464,520,000 square meters of boards 2.5 centimeters thick) and 10,000,000 cords (34,210,000 cubic meters) of pole, post, and fuel material. The 39,000,000 acres (15,783,000 hectares) of grazing land outside the national forests produces a certain amount of forage, which grows chiefly in the early spring, when moisture is most plentiful. This area, being almost entirely without perennial streams, is grazed only in winter, when snow furnishes moisture for livestock, while they are harvesting the forage.

There are about 350,000 cattle, 100,000 horses, and 2,750,000 sheep in Utah. The encroachment of domestic livestock on the native ranges depleted the wild game originally inhabiting this region, and at one time the elk were almost exterminated, but within recent years the mountains have been restocked with deer, elk, mountain sheep, antelope, and other valuable game. A few

privately owned buffalo are being reared on Antelope Island, in Great Salt Lake, but native buffalo were driven from the Great Basin nearly a hundred years ago, the Mormon pioneers having found none in these valleys. A few valuable beaver colonies are protected by law, but artificial changes in streams by roadways, reservoirs, etc., have hampered the restocking of the State's waters by these animals. Bears are still rather numerous, but coyotes, wolves, and other predatory animals and rodents are hunted down aggressively as a protection to livestock and forage. The business of restocking the streams and fresh-water lakes with fish is a large one, the State's waters probably now being as nearly saturated as before settlement days. The fresh and semifresh waters about the estuaries of the principal streams emptying into Great Salt Lake are among the country's most prolific wild game and fowl preserves, and some of the largest sportsmen's hunting clubs are located thereabouts. There is an extensive and elaborate game-bird sanctuary on Bear River Bay.

The general climate of Utah is semiarid, with a definite seasonal march of temperatures. The mean annual temperature of the Salt Lake Valley is about 51° F. The summer days are moderately warm, but the nights are cool, the diurnal range of temperature being comparatively large; and the low relative humidity produces correspondingly low sensible or wet-bulb temperatures. The highest temperatures of record in summer are slightly above 100° F. The frost-free or crop-growing season averages about four months in the agricultural valleys, though on all lower tilled mountain slopes there are reliable downcast nocturnal breezes which make these zones more frost-free, lengthening the season by several weeks or a few months. Such bench lands, so called, are chiefly set to fruit, the valley-bottom lands being planted to vegetables and grains. The mountain valleys have much shorter growing seasons, some of them having frost in every month of the average year.

Precipitation averages about 16 inches (40 centimeters) a year in the principal irrigated farming areas; but it requires another 4 or 5 inches (10 to 12.7 centimeters) for successful dry-land farming, this amount being received on numerous arable bench lands, lying above irrigation waterways. The desert region west of Great Salt Lake receives less than 5 inches (12.7 centimeters) of precipitation a year, but most of the Wasatch Mountains receives more than 20 inches (51 centimeters). In 1918 the Midlake station, on the railroad trestle in Great Salt Lake, received 3.94 inches (10 centimeters) of precipitation, while Silver Lake in the Wasatch Mountains, near Salt Lake City, 70 miles (113 kilometers) distant and about 4,500 feet (1,372 meters) higher, received 46.06 inches (117 centimeters).

March, April, and May are the months of heaviest precipitation. As a rule in June, July, and August the least is received; though over the southern and southeastern portions, especially in the plateau and mountain areas, summer thunder showers occur more frequently. The mountains receive snow from October to April, the winter accumulations of which form the irrigation water supplies for the ensuing season. The Salt Lake Valley receives an average of about 55 inches (140 centimeters) of snow annually, while the mountains get two or three times as much.

The Salt Lake Valley receives measurable amounts of precipitation on about 90 days in the average year and has about 63 per cent of the possible amount of sunshine, 45 per cent in winter and 80 per cent in summer. Wind velocities are moderate, being strongest in afternoon and in summer. Thunderstorms number from three to six a month in summer in the Salt Lake Valley. The morning relative humidity in summer averages about 48 per cent, and the evening about 25 per cent.

Great Salt Lake is the residue of an ancient lake whose surface was poised for many years at each of several lofty horizons, more especially at 625 and 1,000 feet (190 and 305 meters) above the present level, where shore lines that are still plainly discernible were carved on the lower slopes of the mountains roundabout. These shore lines are cut deepest on the southeasterly shores of that ancient lake (which G. K. Gilbert called Lake Bonneville), indicating that then, as now, the highest wind velocities came from the northwest.

There have also been continued and notable fluctuations in the level of Great Salt Lake since the country was settled. The lake was at the lowest stage known about the time the Mormon pioneers came, or from 1847 to 1850, though it was substantially as low in 1905—1.2 feet (0.37 meter) below zero on the present Government gage at Saltair Beach. It was extremely high in the later eighteen-sixties and the eighteen-seventies, the highest observed stage being 14.8 feet (4.5 meters) above the present gage zero in 1877. A stage of 10.8 feet (3.29 meters) occurred in 1886. In 1924 it rose again to 8.2 feet (2.5 meters), the highest in recent years.

Precipitation obviously exerts the major control on lake levels, a series of wet years raising the lake surface and a series of dry years causing it to fall. But there is a lag of a few years in the effect of that portion of the precipitation which percolates deepest into the soils of the lake basin; for a diminishing effect is noted from the precipitation occurring six to eight years back.

The annual oscillation of the lake level is about 15 inches (38 centimeters), but it has been as little as 7 inches (18 centimeters) and as great as 40 inches (102 centimeters), varying with the

ratio between evaporation losses and precipitation gains, and it is always less in years when a steady rise or fall is occurring. The annual crest stage usually occurs in May, June, and July, as a result of the melting of the mountain snows and the consequent flooding of all streams, together with the occurrence of the maximum precipitation for the year about or just before this time. The low stage comes in October, November, and December, when streams are lowest, precipitation least, and evaporation greatest.

The lake water densities correspond to lake stages approximately as follows: At the zero of the United States Geological Survey gage at Saltair Beach, the lake water contains about 26.7 per cent of solids by weight; at 3.0 feet (0.9 meter) about 22.9 per cent, and at 6.0 feet (1.8 meters) about 17.7 per cent.

GEOMORPHOLOGY

By William Morris Davis

BASIN AND RANGE PROVINCE

The Basin and Range province, including eastern California, all of Nevada, western Utah, and southwestern Arizona and occupying about one-tenth of the United States, is bounded on the west by the complex and much eroded fault scarps of the Sierra Nevada and on the east by those of the Wasatch Mountains. It contains more than a hundred isolated ranges, trending mostly north and south, reaching 50 miles (80 kilometers) or more in length and from 8,000 to 12,000 feet (2,438 to 3,658 meters) or more in altitude. Their barren slopes rise over an interlacing network of desert intermont plains, from 5 to 20 miles (8 to 32 kilometers) in width. These detached ranges therefore contrast strongly with the interlocking ranges of the Rocky Mountain system, next to the east, which constitute a true chain and inclose many intramont basins.

The climate of the Basin and Range province is arid; its surface is treeless, except that the higher but not too high slopes, where rainfall is greater, bear forests of open growth. The intermittent water flow of uncounted groups of short, centripetal, wet-weather streams or "washes"—resembling the wadies of the Sahara—is evaporated in the shallow depressions of the intermont plains. A few of the depressions hold lakes, but more of them have dead-level central floors of fine silt, known as "playas," which are occasionally covered with a film of flood water. The Colorado River, rising in the central Rocky Mountains and receiving the intermittent Gila not far above its mouth, traverses

the whole breadth of the province in a southwestward course to the Gulf of California. No other river escapes to the ocean.

Some of the isolated ranges are known to be and many others are supposed to be uptilted fault blocks in various stages of sequential erosion. The desert plains are occupied by imperfectly consolidated deposits, some of the plains having been degraded on detrital deposits and others having been aggraded with similar deposits to their present surface. All the plains are margined with laterally coalescent fans, formed of detritus outwashed from the mountain valleys. Some such fans have a radius of several miles, and all have a gradual increase of slope and of coarseness of detritus toward their apexes at the mountain-valley mouths, where the larger ones may be 1,000 feet (305 meters) higher than the playas to which they drain. Many neighboring playa flats are separated by the master fans of their district. Rain seldom falls in sufficient quantity and over sufficient area to flood a stream from its mountain-valley head near a range crest to its playa goal. Downpours from drifting rain clouds are more commonly so local and so short-lived that floods are formed only along part of a stream course; hence the down-slope transportation of detritus is ordinarily accomplished by relatively short lifts separated by long rests. Still more commonly the drifting clouds let fall so little rain that it nearly all evaporates in the dry air and only a few pattering drops reach the ground; it does not "rain enough to run." On some of the ranges little streams, fed by springs in valley-head glades, lose volume by evaporation along their steep downward courses during the heat of summer days and fail to reach the mountain base; it is then only during the cool nights that they flow to the valley mouth and venture out upon the detrital fans, where their slender current is soon lost in the sievelike gravel; but early the next morning they wither away again under the blazing sun and retreat far up their rocky channels.

The geologic history of the province may be outlined as follows: It is occupied by a vast body of formations of varied composition and of various ages from Cambrian to Jurassic, or Cretaceous, 30,000 feet (9,000 meters) or more in maximum thickness, which rest unconformably on a pre-Cambrian floor of low relief. The compound mass was severely deformed by folds, faults, and overthrusts—by major compressional movements of post-Jurassic date in the west and of late Cretaceous or early Tertiary date in the east; and thus was created a great system of mountains. During later periods of degradation, disturbed from time to time by minor deformations, the mountains were eventually reduced to a surface of moderate or low relief, and on this surface an unconformable cover of detrital (fluviatile or lacus-

trine) or volcanic material (flows and ash beds of rhyolite or basalt) was discontinuously spread out in late Tertiary or early Quaternary time. The province was then broken into elongated blocks on numerous extensional faults of moderate inclination and of repeated displacement along planes indifferent to the deformed structure of the worn-down mountains; and the blocks were diversely displaced. The uplifted or uptilted blocks initiated the existing ranges; the interrange plains resulted either from the degradation of the weak covering deposits from the adjacent uptilted blocks or, where such deposits were lacking, from aggradation of downfaulted interrange troughs with detritus from upfaulted intertrough ranges.

Among the fault-block mountains in the Basin and Range province are ranges in which the mountain blocks, composed of deformed Paleozoic strata, bear on their back slopes unconformable covers of resistant Tertiary basalt, parts of extensive lava flows which were poured out upon the worn-down surface of the Mesozoic mountains while it still lay in the nearly level attitude of degradation; for although the thickness of the flows is not great they extended over large areas. The lava flows, now dislocated, tilted, and more or less eroded, clearly demonstrate the faulting which the underlying masses suffered in their relatively recent upheaval into a second era of mountain existence, after the strong relief of an earlier mountainous era had been obliterated.

Many of the Basin Ranges are to-day of uncertain origin because, however they were uplifted in the cycle of erosion now current, they have since then suffered so large a measure of erosion that their well-developed slopes have been worn back a mile or more, leaving an even rock floor or "pediment," veneered with thin patches of subangular gravel, slanting gently forward to an intermont detrital plain. One of the best examples of such a mountain mass with a surrounding pediment is the Sacaton Mountains, about 40 miles (64 kilometers) south of Phoenix, Arizona. In such ranges no direct evidence of fault-block origin has been found; but inasmuch as manifest fault-block ranges of much later faulting, with lava-covered back slopes, occur not far away, it is eminently possible that the now more eroded and hence older ranges were similarly produced.

OQUIRRH RANGE

The Oquirrh Range, 20 miles (32 kilometers) southwest of Salt Lake City, exhibits a fault-block origin in its best-known, northern part, where its western or fault-scarp face transects

strongly folded Carboniferous strata. Several of its fault-face valleys, opened to submature or mature form within the northernmost part of the mountain mass, are eroded down to accordant junctions with the large detrital fans that are outspread from them on the adjacent plain. But other well-opened valleys a little farther south now hang a few hundred feet above the mountain base and are continued downward by sharply incised clefts in what seems to be a newly revealed and little dissected part of the fault face; hence there a very recent renewal of upfaulting is indicated. The summit highlands of the range, although deeply trenched by its maturing valleys, show such accordance of altitudes together with such indifference of altitude to structure as to permit interpretation as modified remnants of a worn-down surface of moderate or low relief that was developed before block faulting.

The detrital slope or bajada, composed of laterally coalescent fans, which slants several miles eastward from the mountain base into the depression of downfaulting between the Oquirrh and Wasatch Ranges, is a characteristic product of range dissection. The western or fault face of the Wasatch block also exhibits distinct signs of recent upfaulting, although they are less evident than those on the western or fault face of the Oquirrh; for a number of the Wasatch spur-end facets are fairly well preserved, and the detrital fans along the range base are, as a rule, of by no means sufficient size to contain all the detritus that has been washed out from their feeding valleys. This suggests that there, as along part of the western or fault face of the Oquirrh Range, earlier-formed and larger fans were downfaulted when the range block suffered its last movement of upfaulting. And as these vanished fans lay on the eastern or depressed margin of the Oquirrh fault block, which was lately upfaulted along its western margin, that block must as a whole have suffered a slight movement of rotation on a north-south axis.

Such a slight movement of rotation, whereby the original eastward slope of the detrital bajada along the eastern base of the Oquirrh should have been a little steepened, appears to be the cause of a shallow furrowing of the bajada in its upper part by its small mountain-fed, wet-weather streams. The furrows are 100 to 200 feet (30 to 61 meters) wide and 20 feet (6 meters) or more deep, between residual ribs of similar size. The furrowing was done before the waters of Lake Bonneville flooded the intermont plains hereabouts; for the shore of the expanded lake is marked by a line of low bluffs cut into the interfurrow ribs of the bajada and by gravel bars built across the interrib furrows. The gravel bars have suffered little change of form since they were wave

built; their pebbles preserve a polished surface. But the cobbles and boulders which lie on the interfurrow ribs above the limit of wave work and which must have been firm and solid when brought there by floods from the mountains are now so much weathered that nearly all of them have a ragged surface, and some of them are so crumbling that they may be kicked to pieces.

Evidently, then, the time required for the furrowing of the bajada since the latest tilting of the Oquirrh block must be many times greater than the time since Lake Bonneville stood at its highest level. But the time required for the furrowing of the bajada can be only a small fraction of that required for its building, inasmuch as its remaining volume is immensely greater than the volume lost by furrowing. And the time required for the bajada building, which corresponds to that required for the excavation of the maturing valleys in the upfaulted range block, must be much less than the time yet to elapse before the range is reduced to moderate or low relief, like the inferred lowland surface of pre-Oquirrh degradation, long ago upfaulted to the altitude of the range summits. Thus one may gain some idea of the duration of a cycle of mountain erosion; and by assigning appropriate values to the duration of post-Bonneville time and to the three factors by which it must be multiplied to represent the time needed for the demolition of the range, a rough estimate of a cycle of erosion in years may be estimated. Its duration would seem to be, at the very least, several million years, perhaps several scores of million years.

LAKE BONNEVILLE AND GREAT SALT LAKE

Great Salt Lake, a shallow sheet of very salt water (from four to eight or more times as salty as the ocean according as it varies in volume with variations of rainfall), now covers about 2,000 square miles (5,180 square kilometers) of a much more extensive and very smooth, very desert intermont plain at an altitude of 4,200 feet (1,280 meters). The lake has shrunk during the last 80 years, presumably because of the diversion of its inflowing streams for irrigation. It has three larger affluents—(1) the Bear River, rising in a mountainous region 60 miles (97 kilometers) to the northeast and traversing Cache Valley, a beautiful intermont plain inclosed by the low and narrow northern extension of the Wasatch Range, through which the river has cut a narrow gorge; (2) the Weber River, rising 50 miles (80 kilometers) east of the lake and trenching the middle Wasatch in its lower course; the deep valley of this river is now followed by the Union Pacific Railroad eastward from its junction with the Southern Pacific at Ogden, just outside the valley mouth and near the lake, 32 miles (51 kilometers) north of Salt Lake City; (3) the Jordan River,

which comes from the smaller, fresh-water Utah Lake, 30 miles (48 kilometers) south of Salt Lake City, and cuts a gorge through the low Traverse Range on its way north.

The Southern Pacific Railroad crosses the desert plain on approaching the lake from the west; it formerly followed a circuitous course north of the lake, but about 30 years ago a more direct line, 23 miles (37 kilometers) in length, known as the Lucin cut-off, was constructed across the two northern arms of the lake. During its construction the embankment repeatedly sank into the soft silts of the lake bottom and had to be built up again. The railroad makes a slight curve around the south end of the Promontory Range, which separates the two lake arms. On looking from this bend, the western trestle, foreshortened in oblique view, is seen to curve down and disappear at the horizon; the station and water tower at its far end are out of sight. Hence the trestle is, in the words of the late William Hood, under whose direction as chief engineer of the railroad, the cut-off was built, "the only man-made structure which is long enough, straight enough, and level enough to show the curvature of the earth."

During late geologic time, probably coincident with late glacial epochs of the glacial period, a tenfold larger and twentyfold deeper lake (see figs. 1, 2), known as Lake Bonneville, after the explorer who first described its high-level shore lines, occupied all of the irregular intermont basin, on part of the floor of which Great Salt Lake now lies. The outline of the great lake was very irregular; many ranges formed peninsulas and islands in it. Its shore lines are preserved at various levels up to 960 feet (293 meters) above the present lake; and according to Gilbert they indicate two epochs of high water—an earlier and imperfectly recorded but relatively long epoch and a later shorter and remarkably well recorded epoch of somewhat higher water, separated by a short epoch of desiccation. The later high-water epoch is thought to correspond to the latest or Wisconsin glacial epoch, as well-preserved terminal moraines, formed by local glaciers of the Wasatch Range at two points southeast of Salt Lake City, appear to be contemporaneous with the highest Bonneville shore line. The lacustrine epochs are therefore believed to represent times of somewhat lower temperature and greater rainfall than the present epoch. It is important to recognize that these more humid epochs were preceded by a vastly longer arid period, during which many piedmont detrital fans, some of which are of great size, were very slowly formed; for the Bonneville shore lines contour around these fans without greatly affecting them.

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The highest or Bonneville shore line of the later lacustrine epoch appears to have been formed while the greatly expanded lake waters were hesitating at the level of their northward overflow across a pass by which they escaped from the Cache Valley arm of the lake to the Snake-Columbia River system and thus to the Pacific. At that time all the lake-shore mountains had shore-line benches cut along their slopes; many small embayed valleys were shut in by gravel bars; and all the deeper mountain

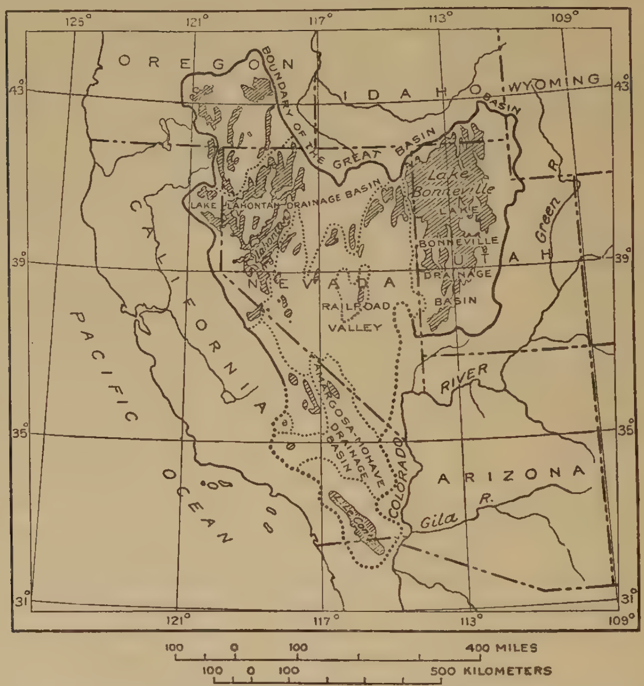

FIGURE 1.—Map showing outline of the Great Basin and the lakes it once contained. Shaded areas show Quaternary lakes; dotted lines show boundaries of drainage basins. From U. S. Geol. Survey Bull. 612, fig. 10, 1915

valleys were invaded by long lake arms which were gradually filled with deltas. The northward outlet, gaining force, cut down about 375 feet (114 meters) in detrital deposits which had previously accumulated in the mountain pass; but as the outflowing river then came upon a somewhat prolonged stretch of resistant rock the lake remained for a considerable time at that level and formed the so-called Provo shore line, the most pro-

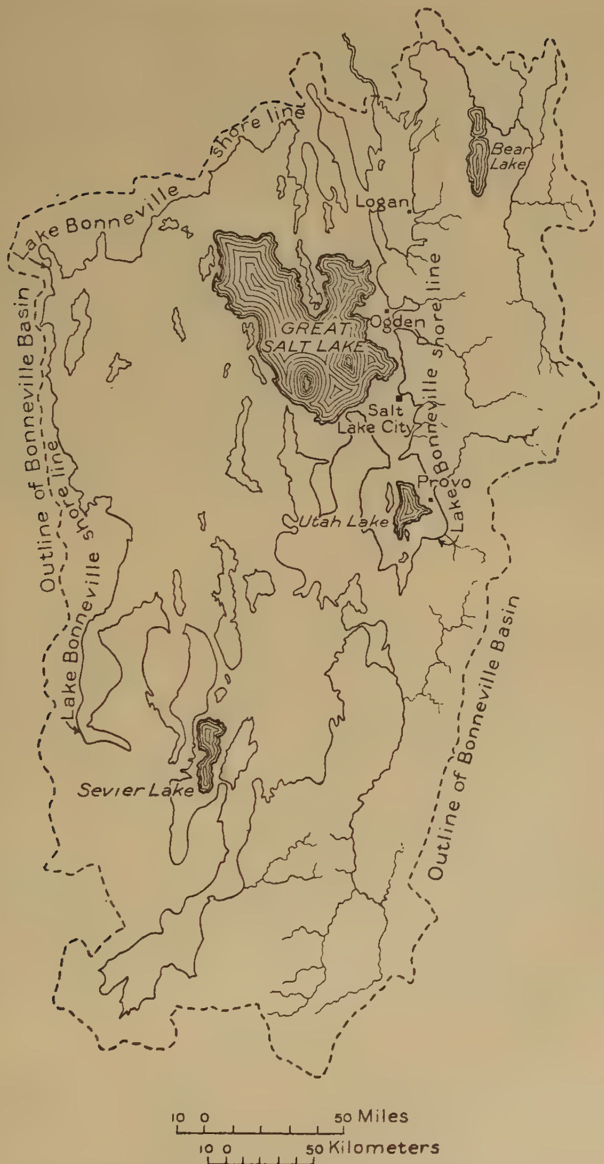

FIGURE 2.—Map of Lake Bonneville. After U. S. Geol. Survey Mon. 1, 1890

nounced of all its records. Along this shore line the broadest benches backed by the highest cliffs were cut on the mountain slopes. A magnificent line of such cliffs is to be seen on the northern slope of the low Traverse Range, 20 miles (32 kilometers) south of Salt Lake City. And at that time deltas, supplied in good part from the higher valley deltas of the Bonneville level, were actively built out to larger size by the chief rivers that flowed into the shallower lake.

Other fainter shore lines were developed during pauses at lower levels as the great lake slowly diminished and shrank away. One of the best localities for examining the whole series of shore lines is on the northeast slope of the Oquirrh Range, easily reached from Salt Lake City. The flat desert west of the existing lake is well sheeted over with the fine sediments of the great lake. Although the present Great Salt Lake is usually taken, at first thought, as the remnant of its great predecessor, it is quite possible that a very arid and lakeless period may have been reached as Lake Bonneville shrank away, and in such case the present lake would indicate a recent and slight increase in humidity.

STRATIGRAPHY

By A. A. L. Mathews

The central Wasatch Mountains, situated almost equally distant from the Colorado Plateau and the Yellowstone National Park, offer one of the best stratigraphic sections in America. Although the section is not complete, every era and period except the Silurian is represented. Moreover, this area includes the type sections of many widely distributed formations, and because of its areal limitations and extensive, easily accessible outcrops, it forms a veritable geologic laboratory.

Most formations in the area were deposited under marine conditions along or near the eastern margin of the Cordilleran geosyncline. After their deposition great structural forces folded the strata into a large syncline (pl. 1), which subsequently was truncated transversely by the Wasatch fault zone. Later erosion has exposed the entire section, which can be easily seen east of Salt Lake City.

PREVIOUS WORK

Many authors have contributed to the analysis of the stratigraphy of the Salt Lake Region; two, however, are outstanding. Clarence King,[1] director of the Fortieth Parallel Survey, published the initial interpretation of the geology of the area in 1876.

[1] King, Clarence, U. S. Geol. Expl. 40th Par. Rept., vols. 1, 2, 1876.

J. M. Boutwell [2] early recognized the different stratigraphic units in the Park City district and published his deductions in 1907 and 1912. To him must be given the credit for laying the foundation of the modern interpretation of the geologic formations with a new nomenclature, as all subsequent work has been based upon his conclusions.

GEOLOGIC SEQUENCE IN THE CENTRAL WASATCH MOUNTAINS

The sequence of strata, from the Archean to the Pleistocene gravel, extends from Farmington on the north to Little Cottonwood Canyon on the south, a distance of over 30 miles (48 kilometers). This section includes a part of the Cottonwood granite stock. Pre-Cambrian and Paleozoic formations form the limbs of the syncline (pl. 1), Mesozoic formations fill the axial trough, the Tertiary sediments lie across the truncated edges of older formations, and Pleistocene gravel flanks the valleys, forming the several lake terraces of the region. The north limb of the syncline rests upon the gneisses and schists at Farmington, and the south limb joins the granite stock near Cottonwood Canyon.

PROTEROZOIC ERA

The rocks representing the Proterozoic era are divisible into the basal complex and the pre-Cambrian quartzites and slates.

The older basal crystalline rocks (Archean) are limited to the border of the Great Basin and are best exposed along the front of the Wasatch Range between Bountiful and Ogden. These rocks consist of a very complex mass of gneisses, schists, some granites, and basic rocks, all highly metamorphosed into a gnarled and banded mass, which is locally cut by numerous pegmatite dikes.

The lowest sedimentary series (Algonkian) is represented by a thick mass of banded quartzites intercalated with thin and thick beds of dark-gray, green, and black slates. The best outcrop of this series occurs along the front of the Wasatch Range near and along Cottonwood Creek.

Just above the quartzites in the Cottonwood area is a bed of very dark gray tillite which weathers to a rusty brown. This tillite is tentatively correlated with the tillite that forms Little Mountain, west of Ogden, though that rock is lighter gray, coarser, and more variable. The age of these tillites may be Cambrian.

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[2] Boutwell, J. M., Stratigraphy and structure of the Park City mining district, Utah: Jour. Geology, vol. 15, pp. 434–458, 1907; Geology and ore deposits of the Park City mining district, Utah: U. S. Geol. Survey Prof. Paper 77, 1912.

PALEOZOIC ERA

The Paleozoic rocks lie unconformably above the older formations and in turn are overlain unconformably by the Mesozoic and Tertiary formations. The paleogeography of the era is best expressed in the threefold topographic conditions that existed during Paleozoic time, produced by an early and a late period of aggradation and a middle interval of degradation. The first period is represented by marine sandstones which crop out as pink quartzites; brownish-gray micaceous, fissile shales; and impure limestones and dolomites of Cambrian and Ordovician age. The second period is indicated by a great unconformity shown by the lack of sediments representing the interval between early Ordovician (Chazyan) and upper Devonian time. The third period is represented by the thick, massive, coarsely crystalline and cherty black marine limestones, thin-bedded carbonaceous shales, and variable sandstones, of Devonian, Mississippian, Pennsylvanian, and Permian age. All these sediments were deposited along the eastern margin of the epeiric seas of the Cordilleran embayment with much of the clastic material derived from the east and southeast.

The study and analysis of the Paleozoic formations have been associated with the development of mining operations throughout the area; consequently a different nomenclature is used in different sections, as shown below:

Stratigraphic formations of the Salt Lake region

[Formational correlation not indicated]

Age	Northern part	Southern part
Quaternary.	Bonneville gravels and lake sediments.	Bonneville gravels and lake sediments.
Tertiary.	Wasatch formation.	Wasatch formation.
Cretaceous.	Frontier formation. Colorado group.	Cretaceous.
Jurassic.	Morrison formation. Twin Creek limestone. Nugget sandstone.	Jurassic.
Triassic.	Ankareh shale. Thaynes group. Woodside shale.	Triassic.
Permian.	Park City formation. Weber formation.	Upper Carboniferous limestones and quartzites.
Pennsylvanian.		

Stratigraphic formations of the Salt Lake region—Continued

[Formational correlation not indicated]

Age	Northern part	Southern part
Mississippian.	Brazer limestone. Madison limestone.	Humbug formation. Pine Canyon limestone. Gardner dolomite. Victoria quartzite.
Devonian.	Threeforks limestone. Jefferson limestone.	Pinyon Peak limestone.
Ordovician.	Swan Peak quartzite. Garden City limestone (?).	Bluebell dolomite. Opohonga limestone. Ajax limestone, including Emerald dolomite member.
Cambrian.	St. Charles limestone. Nounan limestone. Bloomington formation. Blacksmith limestone. Ute limestone. Langston limestone. Ophir shale. Brigham quartzite.	Opex dolomite. Cole Canyon dolomite. Bluebird dolomite. Herkimer limestone. Dagmar limestone. Teutonic limestone. Ophir shale. Tintic quartzite.
Algonkian. Archean.	Banded quartzites, dark gray, green, and black slates. Farmington gneisses and schists.	Pre-Cambrian.

Locally the Paleozoic rocks are highly mineralized, as is shown by the ore-bearing formations of Pennsylvanian age in the Bingham and Park City districts. Both the Weber and Park City formations are widely distributed throughout the region, and both serve as a country rock for the mineralized zones. Mineralization was not limited to the Pennsylvanian formations, for in the Cottonwood and American Fork Canyons rocks of Cambrian and Mississippian age hold the ore.

MESOZOIC ERA

Mesozoic paleogeography varied greatly. The most distinctive physical feature of the era was the shift in deposition from the Cordilleran embayment during the Triassic period to the Rocky Mountain embayment during the Jurassic and Cretaceous periods. Thus the Wasatch Mountains mark in general the eastern border of the most extensive Triassic sea and the western border of the Jurassic and Cretaceous seas. Sediments

resulting from the diastrophism of the era formed, among other kinds, the distinctive and characteristic red beds of the area.

The Triassic, Jurassic, and Cretaceous systems are well exposed in the syncline east of Salt Lake City. (See pl. 1.) The Triassic system, which is remarkably complete, is composed of sediments representing encroaching seas (Woodside shales), distinctly marine limestones (lower Thaynes), shore deposition of retreating seas (upper Thaynes calcareous sandstones), and continental sediments (Ankareh shales and sandstones).

The Jurassic sediments are of three general kinds—the early subaqueous and terrestrial red sandstones (Nugget); the later massive pure marine limestones (Twin Creek formation); and the thin-bedded gypsiferous fissile red shales (Morrison formation). These uppermost red beds are gradational from the Twin Creek limestones and are distinctly separated from the Cretaceous beds. The Nugget sandstone, with its unconformable contacts below and above, represents a long period of erosion, sufficient for the earth movements to shift deposition from the western to the eastern basin. All three formations are exposed in Parleys Canyon.

The Cretaceous sediments crop out above the Mountain Dell Reservoir in Parleys Canyon and mark the western shore of the eastern basin of that time. The coarse conglomerates and sandstones grade laterally and vertically into the brackish-water and marine formations which crop out farther east.

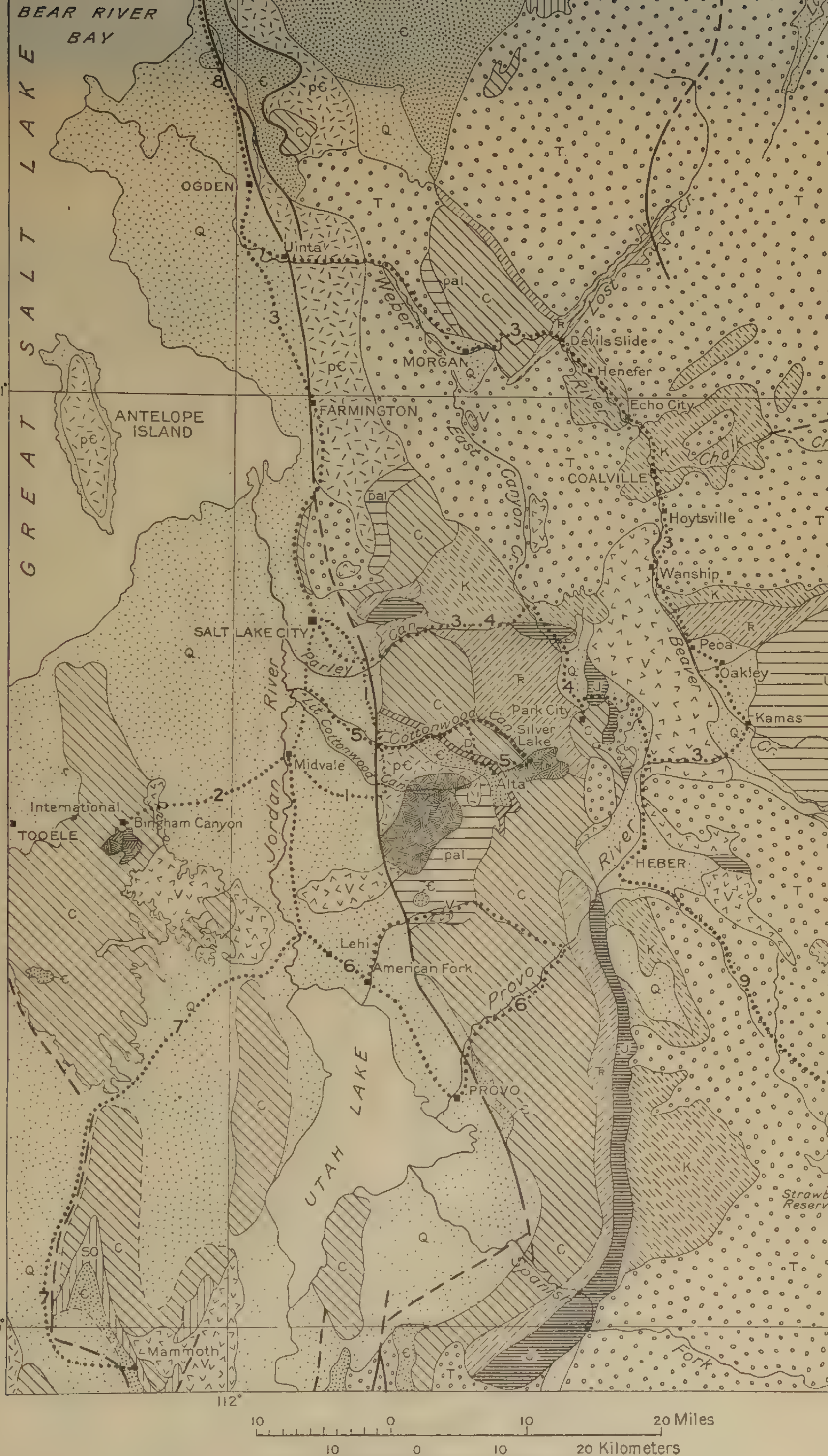
Metalliferous ores are obtained from the Thaynes formation in the Park City district; lime for the manufacture of cement is quarried from the Twin Creek formation in Parleys Canyon and at Devils Slide, and coal is mined from the Frontier formation (Cretaceous) at Coalville.

CENOZOIC ERA

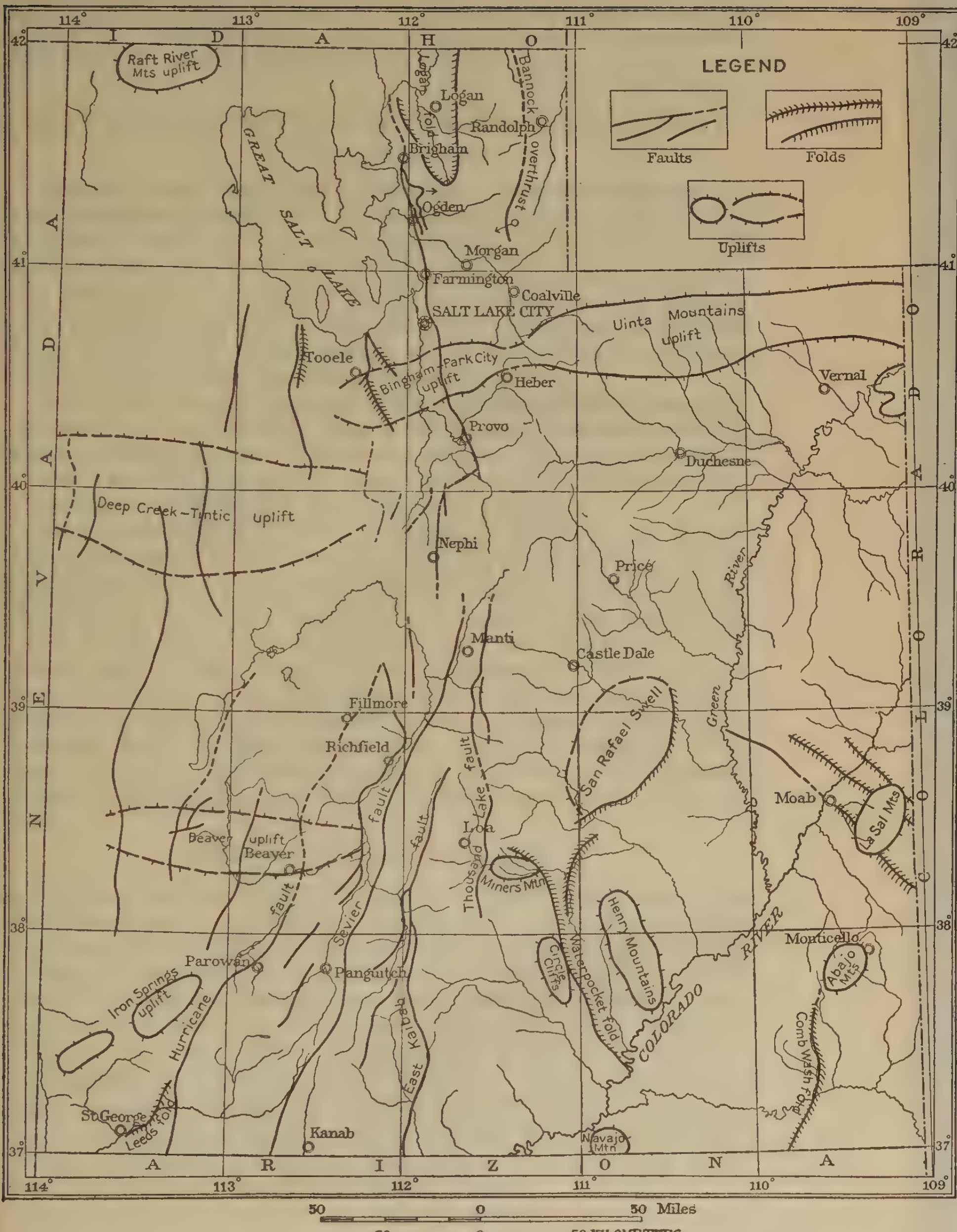
The rocks of Tertiary age are represented by the Wasatch formation, composed of coarse conglomerates and sandstones of terrestrial origin, which are roughly stratified and locally resistant, forming the cap rocks of some high mountains.

Before the deposition of the Tertiary sediments the region was subjected to intense compressional stresses which resulted in folding the pre-Cenozoic strata into great east-west folds. This was followed by a period of erosion. Thus, the Wasatch strata lie nearly horizontal across the truncated edges of all earlier strata, forming one of the greatest unconformities in the region.

Pleistocene gravel, sand, and clay were spread over the valleys of the Great Basin. These form the Bonneville terraces, which are conspicuous topographic features throughout the region.



GEOLOGIC MAP OF PART OF UTAH



POSITION AND RELATION OF MAJOR STRUCTURAL FEATURES OF UTAH

From U. S. Geol. Survey Prof. Paper 111, pl. 11, 1920.

Locally some of the bench gravel has been cemented, forming the Bonneville conglomerate. These deposits flank the mountains and abut the edges of the older formations.

GEOLOGIC STRUCTURE AND GEOLOGIC HISTORY

By Paul Billingsley

The Salt Lake Valley lies in an area of great geologic interest and importance, where the north-south structural trends of the Cordillera cross the east-west trends of the Uinta Mountain uplift. (See pl. 2.) The area of this intersection shows an apparent confusion of structural features, complicated by igneous intrusion and extrusion; but beneath this appearance of disorder lies a sequence of tectonic events which epitomizes the geologic history of the North American mountain belt.

The Uinta axis can be traced for 300 miles (483 kilometers) eastward toward Denver. It is a flat-topped, steep-sided uplift similar to other uplifts of the western Rocky Mountains. Ranges of this type lie in festooned arcs, convex toward the northeast, across eastern Montana, Wyoming, and Colorado.

The Cordilleran axis enters the United States at the Rocky Mountain front in Glacier National Park, Montana, extends southeastward to Yellowstone National Park, turns south along the western border of Wyoming, and finally swings southwestward across Utah into southern Nevada and California. The entire course forms a broad arc, convex toward the east, with the most easterly point in Yellowstone Park and the southern reentrant in southeastern California. It is a topographic boundary between high plateaus on the east, with predominantly flat strata, and low, débris-filled basins to the west, with scattered ranges rising through the detritus and alluvium like an anchored fleet.

STRATIGRAPHIC BACKGROUND

In Algonkian and Paleozoic time (until the Pennsylvanian) the Cordilleran arc coincided with the seaward edge of the western continental shelf of North America, the Canadian shield forming the main land mass to the northeast. West of the shelf were laid down thick marine and shallow-water deposits of Algonkian age, followed by equally thick Cambrian, Ordovician, Devonian, and Mississippian limestones. The Algonkian and the Paleozoic may each aggregate 15,000 feet (4,600 meters) or more. On the shelf itself, however, lapping up toward the shield and surrounding minor unsubmerged areas, were merely the thin marginal edges of the above-named deposits, usually not over one-tenth their full thickness, with many gaps in the column.

In Pennsylvanian time these conditions were abruptly altered. A crescentic belt of uplift across Oklahoma, New Mexico, Arizona, and southwestern Nevada (probably the western continuation of the Appalachian arc) resulted in thick deposition, largely of continental type, in the bordering areas on the north.

In the Salt Lake region the Pennsylvanian formations show striking discordances. The southwestern part of the area contains, below the Weber quartzite, at least 15,000 feet (4,600 meters) of shallow-water marine Pennsylvanian, the "Intercalated series" of early geologic surveys, below which is Mississippian limestone. Northeast of Salt Lake City the "Intercalated"

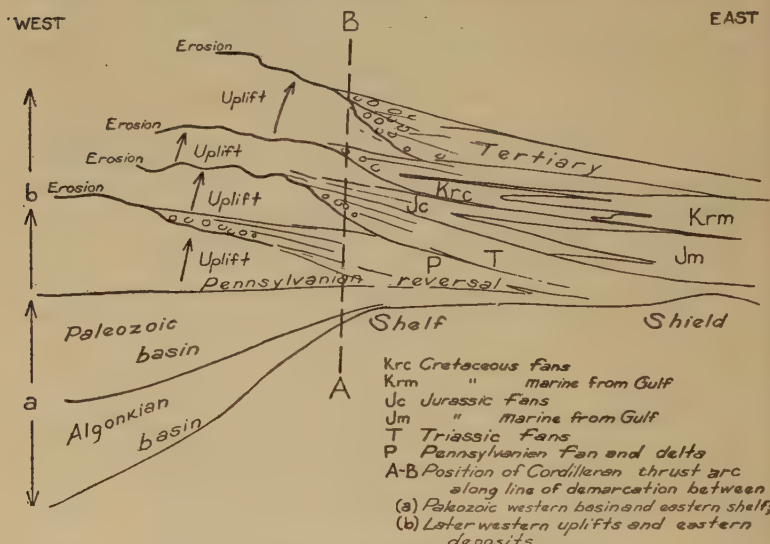


FIGURE 3.—Relations of stratigraphy of Rocky Mountain region to Cordilleran thrust arc

beds are absent, so that in Park City the Weber rests directly upon the Mississippian. Southeast of Salt Lake City Mount Timpanogos shows about half of the normal "Intercalated" thickness. The pre-Weber Pennsylvanian beds—thick to the southwest, thin or absent to the northeast—conform in distribution to the earlier Paleozoic beds. The Weber is the unconformable representative of the new epoch.

All the subsequent formations are of the new type. The western basin became, after Pennsylvanian time, an area of repeated uplift, a source of material for coarse sediments, which accumu-

lated to a great thickness upon the thin Paleozoic formations to the east. Again and again, throughout Mesozoic and Tertiary time, renewed uplift brought a recurrence of this condition, so that at present the western area shows only erosion surfaces to represent this long interval, while the eastern area has many thousands of feet of coarse shore and continental deposits of Triassic, Jurassic, Cretaceous, and Tertiary age, which blend eastward into marine shales formed by northward transgressions of the Gulf of Mexico. The post-Pennsylvanian fans mark an uplift that has taken the position of the Cordilleran trend line.

Figure 3 shows the relation of the eastern deposits to the recurrent uplift on the west.

The Salt Lake Valley lies across the line of demarkation between uplift and deposition. East of Salt Lake City are thick Mesozoic and Tertiary deposits, mainly of continental type. Marine Cretaceous intercalations extend within a few miles of the city. West of Salt Lake City Mesozoic beds are absent.

STRUCTURAL BACKGROUND

The crustal mobility that thus permitted the region to be persistently elevated led to progressive uplift, folding, compression, thrusting, and collapse. This sequence was not strictly contemporaneous throughout the Rocky Mountain region, nor were all the stages everywhere reached. On the other hand, at some points they were repeated.

Uplift throughout later Pennsylvanian and Triassic time culminated in widespread early Jurassic peneplanation. A short period of subsidence spread marine Jurassic beds over the peneplaned surface. Then renewed uplift along the Cordilleran arc produced the belt of Cretaceous fans which merged eastward into shallow-water marine deposits. Minor pulsations of uplift and subsidence throughout this period swung the continental and marine beds successively east or west.

Folding commenced at the end of the Cretaceous period. Local mountain ranges arose, separating basins into which thick coarse deposits of local origin were swept. The festooned ranges of the eastern Rockies and the Uinta Mountains originated in this period of folding. These ranges are characterized by broad open folds. Compressed or overturned folds or thrusts as original pre-Tertiary features are subordinate. The stratigraphic column is that of thin Paleozoic beds resting on a pre-Cambrian complex. The thick Mesozoic beds have been stripped by erosion from the anticlinal axes. Figure 4 shows the position of the principal festoon ranges. It is certain that folding of this age also occurred along portions of the Cordilleran arc. Northeast of Salt Lake

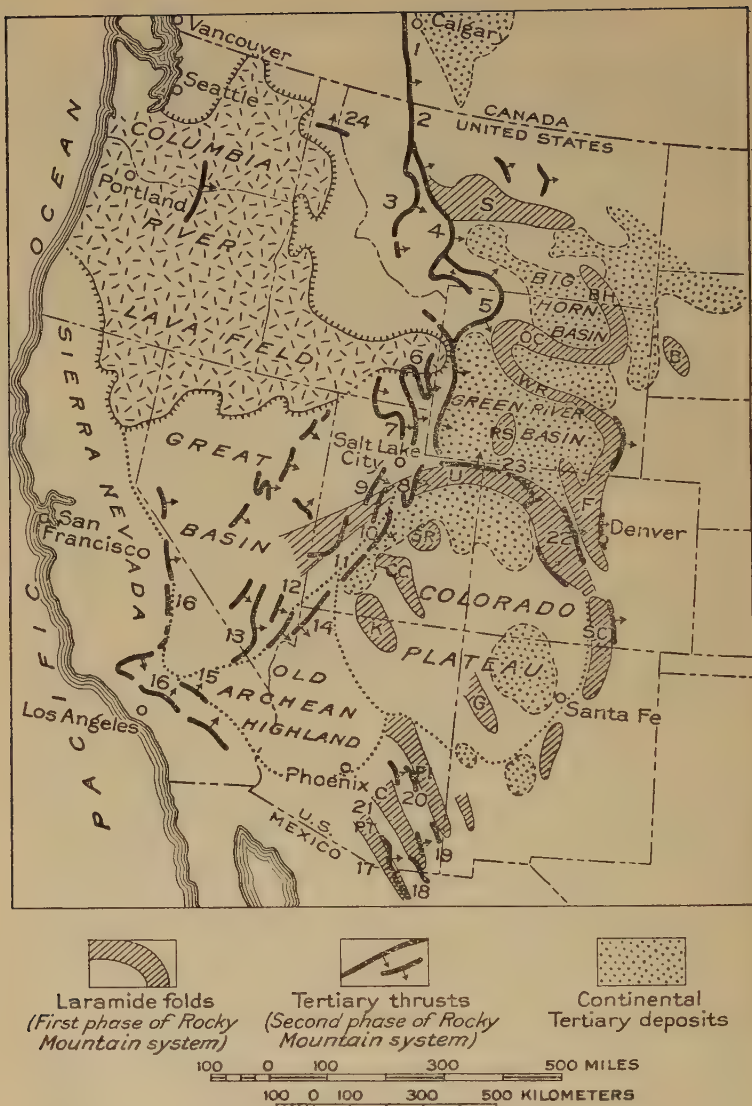


FIGURE 4.—General tectonic features of the Rocky Mountain region

Laramide folds (first phase of Rocky Mountain system): S, Snowy Mountains; BH, Big Horn Mountains; B, Black Hills; OC, Owl Creek Mountains; WR, Wind River Mountains; RS, Rock Springs dome; U, Uinta Mountains; F, Front Range; SC, Sangre de Cristo Range; SR, San Rafael dome; CC, Circle Cliffs dome; K, Kaibab dome; G, Gallup anticline; Pi, Pinaleño anticline; C, Catalina anticline; Pt, Patagonia anticline. Tertiary thrusts (second phase of Rocky Mountain system): 1, Alberta overthrust zone; 2, Lewis and Clark overthrust; 3, Philipsburg overthrust; 4, Little Belt-Bridger thrust; 5, Absaroka overthrust; 6, Bannock overthrust; 7, Willard thrust; 8, Cottonwood thrusts; 9, Stansbury Mountain thrust; 10, San Pete Valley thrust; 11, Cedar City thrusts; 12, Mormon Mountain thrusts; 13, Goodsprings Mountain thrusts; 14, Virgin Mountain thrusts; 15, Calico Mountain thrust; 16, thrust line, eastern edge of Sierra Nevada; 17, Patagonia thrusts; 18, Gold Hill thrust; 19, Gleeson thrusts; 20, Mescal Mountain thrusts; 21, Catalina Mountain thrusts; 22, Leadville thrusts; 23, North Uinta thrusts; 24, Osburn fault.

City, for example, near the Wyoming line, are north-south pre-Tertiary folds which have been subsequently intensified and overthrust.

Compressed folds and thrusts represent as a rule a specialized late stage of the tectonic sequence. They are, with few exceptions, concentrated along a special belt—the Cordilleran arc. (See fig. 4.) In contrast to the open folds of the festoon ranges, this belt has a section made up of compressed folds, overturned to the east, with large overthrust faults. The development of these structural features was long continued, with recurrent episodes of intensity that varied in time in different portions of the belt. Throughout its course, however, the activity persisted well into the Tertiary, so that thrust blocks overrode the Tertiary lake beds in Montana, the conglomerates and oil shales of western Wyoming and Utah, and the lake beds of southern Nevada and southeastern California. The compression and thrusting developed most fully along a broad arc that subtends the sharper curves of the folded ranges; and the development extended into later times.

Collapse has been a widespread phenomenon to the west of the Cordilleran arc. This region is lower than that east of the arc, and it is broken by countless north-south normal faults into tilted blocks which are largely buried beneath desert débris and lava. These normal faults are geologically recent. They offset Quaternary lavas which rest upon the peneplaned surface of folded and compressed formations. They are the dominant topographic control of the Salt Lake region. The Wasatch fault, one of this type, makes the scarp of the Wasatch Mountains, facing west on the Salt Lake Valley. Others outline the Oquirrh Range, across the valley.

IGNEOUS BACKGROUND

The Snowy, Big Horn, and Uinta Mountains are unaffected by igneous activity. The Cordilleran arc, on the other hand, is marked by a succession of igneous centers. In Montana, in the area where the arc crosses the Snowy Mountain axis, are the Boulder batholith and its associated lesser intrusions and extrusions, of Eocene and later age. In northern Utah, at the crossing of the Uinta axis, are the Park City, Cottonwood, Bingham, and Tintic intrusions and extrusions, of middle Tertiary age. Farther south in Utah, at the crossing of the Torrey axis, are the Marysvale, Beaver, Milford, and Frisco Tertiary intrusive and volcanic rocks. Between these axes, where the arc traverses a thicker stratigraphic section, volcanism has been very rare.

SALT LAKE VALLEY

The Salt Lake Valley contains, within a compact area about 60 miles (97 kilometers) in diameter, all the major stratigraphic, structural, and igneous elements above outlined. This area is shown on Figure 3.

In the western mountains (Oquirrh and Tintic) are found the thick lower Paleozoic and lower Pennsylvanian formations of the old marine basin. In the eastern mountains (Wasatch) are the thin Paleozoic deposits of the shelf.

East of Salt Lake City is the Uinta axis, a broad open flat-topped anticline of pre-Tertiary age. The Eocene oil shales were formed in two separate basins, one north and one south of this range. Toward Salt Lake City this axis becomes corrugated with cross folds, which pass at Alta into a compressed belt with thrust faults. The Salt Lake Valley slices across the axis, which is here dropped 6,000 to 8,000 feet (1,800 to 2,400 meters) by the Wasatch fault; but the Uinta anticline can be followed beyond by observing formations and dips in the western ranges.

The Cordilleran thrust belt, which is the dominant structural feature in northeastern Utah and along the Wyoming line, is distorted by the massive beds on the Uinta axis, making a sharp reentrant to the west as it crosses this uplift. Within this reentrant are the sharp transverse accordionlike folds. These folds involve Tertiary formations and so fix the culmination of Cordilleran compression as subsequent to the Uinta uplift.

Still later are the normal north-south faults, which outline the Wasatch and other ranges of the region. Tilting accompanied this late faulting. The floor of Tertiary deposits in the Wasatch Mountains now slopes to the east, like the crests of the range. The eastward dip of the Cottonwood thrusts may be due to this comparatively recent tilting.

Three igneous centers are found in the region—in the Park City-Alta area, at Bingham, and at Tintic. In each there is evidence that the leakage of magma from the depths has been facilitated by excessive deformation of the beds. At Park City and Alta the Uinta axis is intersected by cross folds and thrusts; at Bingham there is a sharp bend on the north flank of the Uinta axis; and at Tintic a northeast Uinta fold is driven in and overturned on the west by north-south Cordilleran thrusting.

ECONOMIC GEOLOGY

By John M. Boutwell

Utah is the mining and metallurgical center of the West. The mineral resources of this State afford an annual production valued at $120,000,000 and dividends aggregating $38,000,000. Despite its comparatively small area (84,900 square miles, or 220,000 square kilometers) and small population (507,847), Utah ranks as one of the three or four chief metal-producing States in the country. Thus in 1929 Utah's metal production was first in silver, second in copper, second in lead, fourth in gold, and fifth in zinc, and second in mine dividends (12).[3] Utah has the largest copper mine, some of the largest lead-silver mines, the largest concentration mills, and the largest copper smelter in the country. The mining industry occupies one-third of the total employees and four-fifths of the railroad tonnage. Of Utah's population in 1930, 47.17 per cent are basically dependent on metal mining and 9.08 per cent on coal mining—a total of 56.25 per cent on mining (20).

GENERAL FEATURES OF ORE DEPOSITS

Within the geologic formations of this State, associated with mineral deposits, 183 distinct minerals have been recognized (10). Some of these mineral deposits are among the largest and richest of their kind known. The reason for their occurrence lies in the favorable combination of the essential geologic factors. In general, adequate and suitable sedimentary formations, suitable fracturing and fissuring, and extensive igneous intrusions by great masses of suitable magmas into necessary sediments under suitable conditions of temperature and pressure have produced these valuable mineral deposits.

The principal known ore deposits in Utah are inclosed in older rocks, either igneous or sedimentary, in intimate association with intrusive stocks that are commonly dioritic or monzonitic. They embrace disseminated deposits of copper ore and vein deposits of gold, copper, silver, lead, and zinc within the intrusives; contact deposits of copper, gold, and iron; and veins and replacement deposits of copper, lead, silver-lead, zinc, gold, and quicksilver connected with fissures within sedimentary rocks. The deposits contemporaneous with inclosing rocks are in this region comparatively unimportant; they include only placers. The more valuable deposits are associated with apically truncated stocks and their connecting dikes; the deposits associated

[3] Numbers in parentheses refer to bibliography, pp. 31–32.

with deeply truncated stocks or with laccoliths are of slight commercial value (10).

The combinations of factors most favorable to the deposition of valuable ore deposits appear to be particularly persistent in the western half of the State. The principal metallic deposits have been found in three localities—the Bingham, Park City, and Tintic districts; others occur in smaller districts, such as Cottonwood, Frisco, Ophir, and Stockton.

PRINCIPAL METAL-MINING DISTRICTS

The Bingham district, 20 miles (32 kilometers) southwest of Salt Lake City, in the eastern slope of Oquirrh Range, was the site of the earliest mining location in the area now known as Utah and at present contains the Utah Copper mine, the leading copper producer on this continent, and such productive lead-silver-zinc mines as the United States, Utah Apex, Utah Delaware, Ohio Copper, Utah Metal and Tunnel, Bingham Mines, and Bingham Prospect. The 3,300 level of the Utah Apex, 4,300 feet (1,311 meters) below the surface and 4,300 feet above sea level is the deepest mine working in the State.

The Utah Copper mine, working, chiefly by open-cut methods, low-grade copper ore, disseminated through a stock of monzonite (5), with an estimated ore reserve of 640,000,000 tons of 1.04 per cent copper, has mined 193,868,751 tons of ore, from the proceeds of which $203,481,102 has been paid in dividends. Its daily output is 50,000 to 60,000 tons of an average copper content of 0.994 per cent, or 19.89 pounds (9 kilograms) to the ton. In 1927 this property yielded 90.70 per cent of the copper produced in the State; in 1928, 15 per cent of the total copper produced in the United States, or one-twelfth of the world's output. The value of the total production from this district is $800,000,000.

The Park City district (6), whose mines now work lead-silver-zinc ore, is 32 miles (53 kilometers) by road southeast of Salt Lake City, high in the eastern slope of the Wasatch Range. This district, a great and steady producer of silver and lead from lodes and beds, has yielded an output valued at $250,000,000, from which dividends amounting to $75,000,000 have been paid (6). This camp has been noted for the occurrence of large bodies of high-grade lead-silver ore with unusual persistence on the strike and in depth; the mines are now working in ore of concentrating grade. The great mines opened in the main productive ground are owned and operated under two consolidations. The Silver King Coalition Mines Co. owns about 4,000 acres (1,619 hectares) embracing roughly the western half of the district, and the Park Utah Consolidated Co., including the old Ontario mine, owns

roughly the eastern half of the district. Four long tunnels, 1, 2, 3, and 5 miles (1.6, 3.2, 4.8, and 8 kilometers) in length, together with shafts down to 2,000 feet (610 meters) in depth, afford access to the mine workings. The deepest level is the Ontario 2,000 level, and the deepest accessible level is the King 1,950 level, which is in places about 4,000 feet (1,219 meters) below the surface. Large ore reserves, excellent probabilities for new ore in certain great mines, and favorable possibilities in outlying prospects assure a good future for the district.

The Tintic district (16), 93 miles (150 kilometers) by road southwest of Salt Lake City, in the East Tintic Mountains, has produced lead, silver, gold, and copper ores to an aggregate value of about $300,000,000. These ores occurred as veins, beds, and pipes in sediments ranging in age from Lower Cambrian to Mississippian. The production in earlier days from the great zones of the western part of the district is now giving way to that from valuable ores found in the extension of mineralized ground eastward beneath extrusives. The complex character of the ores, due largely to deep enrichment, has long made Tintic a Mecca for mineral collectors. A new silver jarosite intergrown with large bodies of anglesite, occurring in Middle Cambrian limestone, was recently discovered in the Tintic Standard mine and has raised the value of some of the ore to $64,000 a carload, and more recently a considerable body of valuable gold ore in a zone of fractured Cambrian quartzite has been developed. Current exploration holds important possibilities for the extension of the productive life of this district.

The Cottonwood districts (10), embracing the headward portions of Cottonwood, Little Cottonwood, American Fork, and Snake Creek Canyons, are 20 to 30 miles (32 to 48 kilometers) southeast of Salt Lake City along the crest of the central Wasatch Range. They have produced from veins, replacement bodies, and contact deposits in sediments ranging from Cambrian to Mississippian in age some remarkably rich ores of silver, copper, lead, and gold to an aggregate value of $33,000,000. In these districts a remarkable series of contact-metamorphic minerals occur along the contact between limestone and intrusives, particularly extensive dioritic bodies.

In the Frisco district (7), in southern Utah 10 miles (16 kilometers) west of Milford, the Hornsilver mine produced from a unique vein associated with Cambrian limestone, monzonite, and extrusive rocks, over $50,000,000 worth of high-grade silver ore from the greatest concentration of value in small space known in Utah.

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Deposits of iron of commercial value occur in the Iron Springs district, near Cedar City, about 250 miles (402 kilometers) southwest of Salt Lake City, and in the Bull Valley district, about 25 miles (40 kilometers) southwest of the Iron Springs district; and small shipments have been made from several other relatively small deposits, such as those in the Antelope Range and the Dragon mine at Tintic (2, 15).

The iron in the Iron Springs district (15) has been estimated to contain in the surface portion more than 50,000,000 tons. It is a mixed ore made up of 70 per cent magnetite and 30 per cent hematite, with low phosphorus and inconsequential amounts of copper and titanium. The ore averages 57 per cent iron. The principal deposits occur near contacts of intrusive porphyritic andesite and limestone, partly replacing the limestone, and to a minor extent in fissures in limestone and andesite in association with contact minerals. They are thus regarded as contact deposits formed by laccoliths of intrusive andesitic magmas in adjacent Carboniferous limestones. The Bull Valley deposits are similar in character, occurrence, and origin but are more inaccessible and less developed.

Large tonnages of these deposits in both districts as well as of a semicoking coal in Carbon County are owned by the Columbia Steel Co., a subsidiary to the United States Steel Corporation. At Provo, 45 miles (72 kilometers) south of Salt Lake City, the company operates an efficient modern plant including blast furnaces, producing annually 150,000 tons of high-grade pig iron, and by-product coke ovens (Koppers), producing annually 300,000 tons of coke.

METALLURGY

Salt Lake City is one of the principal centers of nonferrous smelting (19). In 1929 the great Magna and Arthur mills, about 15 miles (24 kilometers) southwest of Salt Lake City, each with a daily capacity of 30,000 tons of ore, treated a daily average of 50,210 tons of the Utah Copper ores and produced a high-grade copper concentrate. Mixed sulphide ores, containing silver, copper, lead, zinc, and gold, were treated at the custom flotation plants of the International Smelting Co. (daily capacity 1,200 tons) at International, of the United States Smelting & Refining Co., and the American Smelting & Refining Co. at Midvale (capacity 1,000 tons), and of the Combined Metals Co. at Bauer (capacity 700 tons). The product of their own mines is treated by the Silver King, Chief Consolidated, and Utah Apex flotation mills and the Park Utah Consolidated gravity and flotation mill. In short, in 1929 the Utah concentrating plants treated 19,211,775

tons of ore, which yielded 69 per cent of the total gold output of the State, 94 per cent of the copper, 65 per cent of the lead, and most of the zinc (12). During this year 99.31 per cent of the milling ore was treated by flotation.

These concentrates together with the crude ore are smelted at the great plants of the American Smelting & Refining Co., the International Smelting Co., and the United States Smelting & Refining Co., in the Salt Lake Valley. The copper smelter of the American Smelting & Refining Co. at Garfield, treating the Utah Copper concentrates, produces more copper daily than any other smelter in the world. This company also operates a lead smelter at Murray. Both lead and copper ores are handled at the International plant. The United States plant at Midvale, in addition to treating lead ores, has an arsenic department.

NONMETALLIC DEPOSITS

COAL

One of the largest known deposits of high-grade bituminous coal occurs about 100 miles (161 kilometers) due southeast of Salt Lake City, in the Carbon-Emery region. The workable coal is estimated to underlie 13,130 square miles (34,000 square kilometers) and to aggregate 196,000,000,000 tons. More than three-fourths of the coal output from Utah is taken from seams ranging from 8 to 17 feet (2.4 to 5.2 meters) in thickness, and one-third comes from seams not less than 16 feet (4.9 meters) in thickness. Nearly all of the Utah coal is obtained from the Book Cliffs and Wasatch Plateau fields, underlying the great Uinta Basin between the Wasatch Plateau, in central Utah, and Crested Butte, in western Colorado. It occurs almost entirely in the Mesaverde formation (Upper Cretaceous), in three or four workable seams 4 to 28 feet (1.2 to 8.5 meters) thick in a general series of alternating beds of sandstone and clay 200 to 700 feet (61 to 213 meters) thick (11).

The coals are low in ash, moisture, and sulphur and high in heat value (about 13,000 British thermal units); are hard, nonslaking, and high in volatile matter; and are mostly noncoking. The average annual production is 5,000,000 tons, of which 500,000 tons is converted into coke for use in near-by metallurgical plants, and the remainder is consumed locally and in neighboring States.

SALINES

Salt.—From the waters of Great Salt Lake, containing 13 to 18 per cent of salt, 80,000 tons of salt is produced annually by the solar process. Rock salt is quarried from beds of Tertiary age at several localities near Salina, in Sevier and Sanpete

Counties. Rigid white crystalline porous salt occurs in two areas—one of about 150 square miles (389 square kilometers) along the Western Pacific Railroad adjoining Salduro, west of the Oquirrh Range, and the other of 25 square miles (65 square kilometers) between the Desert Range and Pilot Mountain. The salt of the larger area yields 36.85 per cent of sodium and 58.90 per cent of chlorine. These two salt areas are regarded as confirming Gilbert's conception of the warping of the lake bottom of Lake Bonneville (17).

Potash.—Brines from the Great Salt Lake Desert, both from salt crusts and from underlying muds, contain potash and magnesia and in 1920 afforded a considerable production of potash. Extensive deposits of alunite (9) near Marysvale, in the Tushar Range, occurring as veins containing 11.5 per cent of potassium oxide, were worked during the World War for potassium. Experiments are now being directed to determine the possibility of utilizing alunite and also of using the finely ground tailings from the Bingham monzonitic stock as a commercial source of potash. Carnallite and sylvite have been reported from borings in Grand County.

OIL

Geologic formations that have afforded oil in commercial quantities in adjoining States are extensively represented in Utah. At several localities where these formations show favorable structure, particularly in the eastern and southeastern parts of the State, drilling for oil has been conducted, and in certain holes small flows of a few barrels a day were obtained (13, 14). No commercially valuable flow has yet been developed, but drilling is still being carried on at various points, as near Cisco, Utah, for Pennsylvanian beds; at Virgin (1) for the Lower Triassic (Moenkopi); in Butler Valley, 80 miles (129 kilometers) south of Marysvale, in the southeast corner of Utah, on the Boundary-Ruth fold, for Pennsylvanian sands; northwest of Salt Lake City in Salt Lake Basin (4) and north of Great Salt Lake for Pennsylvanian beds.

Of great potential value as a source of oil and by-products are the thick oil-bearing shales of the Green Mountain formation (Eocene), which underlie the Uinta Basin (22, 23, 24). According to Winchester, "a workable thickness of good shale is present at nearly every place examined along the south side of the Uinta Basin in Utah." It is estimated that "the Utah portion of the basin alone contains sufficient shale to produce 42,800,000,000 barrels of crude shale oil with perhaps 500,000,000 tons of ammonium sulphate" (23, p. 28). The higher cost of working the shale oil, however, prohibits its utilization until flowing oil has been exhausted.

In the western portion of the Uinta Basin large deposits of the hydrocarbons gilsonite, elaterite, tabbyite, albertite, wurtzilite, nigrite, and ozokerite occur as veins within either the Wasatch or the Green River formation (Eocene).

Other nonmetallic minerals, such as gypsum (anhydrite), limestone for cement and for lime, sand, gravel, clay, phosphate rock, bentonite, and diatomaceous earth, are found in commercial grade and quantity at many places in Utah.

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Excursion 1.—WASATCH FRONT

By John M. Boutwell[4]

ABSTRACT

The Wasatch Mountains form a lofty north-south range made up of 20,000 feet (6,100 meters) of sedimentary formations, about half pre-Cambrian and half Cambrian to Jurassic, strongly folded along north-south axes and faulted by overthrusting along north-south courses. In the central part of the range these north-south trends are interrupted by a dominant syncline with east-west axis and an east-west chain of intrusive rocks according in trend and position with the northern limb of the adjoining Uinta Range. The Wasatch Range, terminating the Great Basin on the east and rising abruptly from the basin (altitude 4,200 feet, or 1,280 meters) for more than 7,000 feet (2,100 meters), falls off gently on the east about 3,000 feet (914 meters) to the high plateau. The range is dissected by numerous streams which head east of the divide and flow west through narrow, steeply graded canyons. A downthrow on the west of not less than 10,000 feet (3,050 meters) has taken place along a great normal north-south fault or chain of faults. Around the base of this slope a series of well-defined shore lines record the successive levels of Lake Bonneville, which in Pleistocene time occupied part of the Great Basin. Three levels are particularly well recorded—the Bonneville at 1,050 feet (320 meters), the Provo at 625 feet (190 meters), and the Stansbury at 315 feet (96 meters) above Great Salt Lake. Within the Great Basin unconsolidated materials now fill the intermont valleys. Since the disappearance of Lake Bonneville and of the valley glaciers that fed it, movements recurring along the Wasatch fault have cut and displaced the lake beaches and the lateral moraines.

GENERAL FEATURES

The view from the State capitol in Salt Lake City embraces a characteristic segment of the Wasatch Range on the east as well as an extended prospect over the plain of Great Salt Lake on the west and of several Basin Ranges, the nearest of which is the Oquirrh Range, 15 miles (24 kilometers) to the southwest. The lower slopes of all the mountains are delicately contoured with the shore lines of the extinct Lake Bonneville.

The Wasatch front here falls back in a bight, some 25 miles (40 kilometers) in chord length with a 5-mile (8-kilometer) retreat, between the strong City Creek salient on the north and a less marked salient on the south; there the Traverse Range stretches

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[4] This sketch is based on contributions by W. M. Davis on geomorphology, A. A. L. Mathews on stratigraphy and paleontology, and R. E. Marsell on itinerary, and on the writer's own studies.

across the aggraded intermont trough lying between the Wasatch and Oquirrh Ranges and thus separates the basin of fresh-water Utah Lake, 4,450 feet (1,356 meters) in altitude and 25 by 10 miles (40 by 16 kilometers) across, 40 miles (64 kilometers) away on the south, from the much larger and somewhat lower basin of Great Salt Lake (altitude 4,250 feet, or 1,300 meters) on the north. The two basins are connected by the northward-flowing Jordan River, which has eroded a gorge through the Traverse Range.

The 25-mile bight in the Wasatch front may be divided into a 13-mile (21-kilometer) southern bight and a 12-mile (19-kilometer) northern bight, each made up of smaller bights. A large part of the range adjacent to the two bights is occupied by a series of Algonkian to Jurassic strata, some 30,000 feet (9,000 meters) in thickness (36),[5] bent into a huge syncline by early Cretaceous compression between Archean abutments on the north and south. The middle of the syncline is locally upfolded into a subordinate anticline, thus giving the medial strata the double bends of a W. The axis of the syncline trends northeast and has a decided pitch in that direction, in consequence of which the strata on the north side of the syncline strike more to the north and those on the south more to the east. (See fig. 5.)

After a long period of erosion the synclinal mass was transected by a roughly north-south normal fault of late Tertiary date (fig. 6), with a displacement of about 10,000 feet (3,050 meters) (31), on which the east side was relatively raised and eroded while the west side was depressed and buried. The erosion of the upfaulted mass has been greatest along the weaker strata, in which steep-sided canyons have been excavated by revived streams, which had probably gained their subsequent courses during the cycle of erosion that preceded the faulting. The harder strata have suffered much less erosion, so that they now survive in strong ridges with altitudes of 7,000 to 9,000 feet (2,100 to 2,700 meters). These ridges are abruptly cut off by the frontal fault, on descending to which they broaden to fairly distinct triangular facets thought to be inherited from the originally steeper fault face, although now worked back almost to a soil-holding declivity of somewhat less than 40°.

The rock waste supplied by erosion consequent on the major upfaulting of the mountain mass must be of enormous volume, sufficient to build large detrital fans at the valley mouths; yet such fans are seldom seen. The largest ones are found some 70 miles (113 kilometers) to the south, where the valleys are not larger but where a long period of postfaulting quiescence is in-

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[5] Numbers in parentheses refer to bibliography, p. 45.

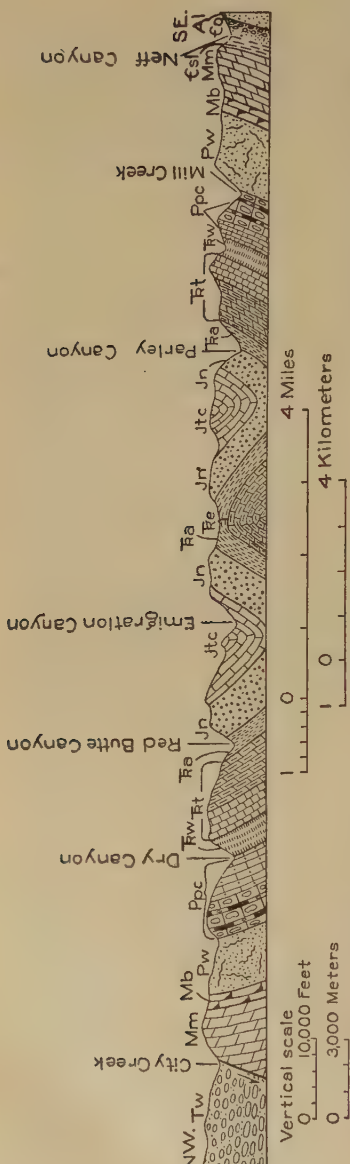

FIGURE 5.—Sketch structure section of formations in Fort Douglas area. Tw, Wasatch; Jtc, Twin Creek; Jn, Nugget; Ŧa, Ankareh; Ŧe, Emigration; Ŧt, Emigration and Pinecrest; Ŧw, Woodside; Ppc, Park City; Pw, Weber; Mb, Brazer; Mm, Madison; €sl, Cambrian shale and limestone; €q, Cambrian quartzite; Al, Algonkian. By A. A. L. Mathews

ferred. Along the greater length of the range most of the valleys are fronted by relatively small fans and some by no fans at all. It is therefore thought that the fans that should have been built forward in consequence of the major upfaulting have been depressed by minor faulting on the downthrown side of the fault, which at the same time presumably gave additional uplift to the upthrown side; and it is also found that many of the later formed smaller fans have been more or less broken and depressed by recent faulting. It is possible that the original major faulting, which is to be measured in thousands of feet, was made up of many minor movements, measured in hundreds or tens of feet—in other words, that the total faulting was accomplished through a long period of time in many moderate or small movements and was accompanied by much erosion. But the effects of early and great, intermediate and late, and small movements are manifest in many places.

It seems that the mountain-making fault did not raise the eastern mass over the western mass by a single uniform move-

ment all along its length but let the western mass sink piecemeal in separate parts while the eastern mass rose more continuously; thus the sinking mass headed against the rising mass in concave bights from 1 to 10 miles (1.6 to 16 kilometers) across. The trace of the fault as followed along the mountain mass to-day is therefore neither rectilinear nor extremely irregular but is composed of a considerable number of entrant curves meeting in blunt cusps. The most marked curve makes almost a semicircle with a diameter of about 11 miles (18 kilometers); it lies some 50 miles (80 kilometers) south of Salt Lake City.

Specific descriptions of the lesser or secondary bights composing the larger bights are given in the detailed itinerary.

The prevailing conception of the faulting along the Wasatch front, first announced by Emmons (29), is well expressed by Gilbert in his final statement, published after his death and presenting the matured conclusions to which he was led by his extensive investigations (31). He conceives that

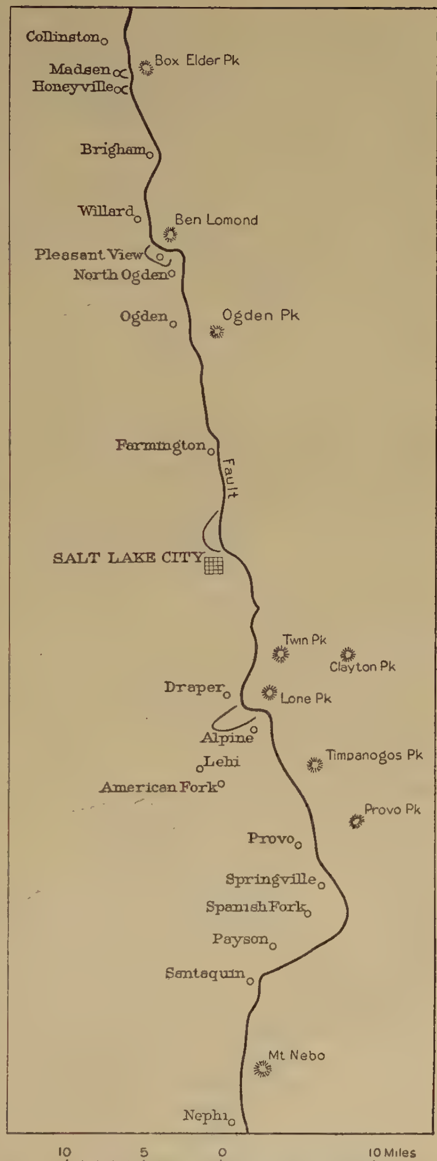

FIGURE 6.—Map of frontal fault of Wasatch Range. From U. S. Geol. Survey Prof. Paper 153, fig. 12, 1928

the Wasatch front has been formed by normal faulting on a wide zone of generally parallel faults, trending slightly west of north along a crooked course for more than 80 miles (129 kilometers) and dipping west, the west or hanging wall being dropped about 10,000 feet (3,050 meters), and portions of fault blocks, included in the fault zone, which lagged in dropping, forming westward-extending salients. In his supplementary explanation of the deflections or crooks in the course of the fault zone, Davis (28) considers them as indicating that the displacement took place along a composite or interlocking chain of crescentic faults.

A special interesting feature of this region is Great Salt Lake and its development from the former extensive sea Lake Bonneville. The unique sensation of swimming in the densely saline, buoyant water of this lake will be enjoyed.

The history of Lake Bonneville, as worked out 50 years ago by Gilbert (30), may be here summarized. Two epochs of high water and humid climate, preceded, separated, and followed by epochs of aridity, were determined. The shore lines of the first humid epoch have not been identified, but the lake-floor deposits then formed consist of a heavy yellow clay, the shoreward extension of which rises within 90 feet (27 meters) of the highest level reached by the lake of the second humid epoch. The intermediate epoch of aridity is indicated by a surface of erosion discordantly overlain by white marl of moderate thickness, the deposits of the second epoch of moist climate and high water. Near the margin of the basin the clay and the marl are separated by a wedgelike subaerial deposit of gravel similar to the gravel which has been washed down upon the marl in the present postlacustrine arid epoch. It is the shore lines of the lake formed in the second humid period that are seen contouring the mountain slopes to-day. It has been inferred from the lake deposits and associated topographic features that the first lake endured several times longer than the second and that the interlake arid epoch was decidedly longer than the postlake epoch. The second lake, named Bonneville after the explorer who first recognized it, had an extremely irregular shore line, diversified by many peninsular and insular mountain ranges. Its area was nearly 20,000 square miles (51,800 square kilometers), or about ten times the area of Great Salt Lake; and its highest shore line had a length of 2,550 miles (4,104 kilometers) at an altitude of over 1,000 feet (305 meters) above the present lake and about 5,000 feet (1,524 meters) above sea level.

The Bonneville shore line, which is prominent because it is the highest rather than the strongest of the series, was formed while the lake stood at the level of overflow across a pass in the mountains to the north, which led its waters to the Snake and Columbia Rivers and the Pacific Ocean. After the outlet pass was

slowly cut down 375 feet (114 meters) the sinking lake long remained at that lower level, because much resistant rock was then encountered and probably also because the volume of outflow was then diminishing. At this level the so-called Provo shore line, the strongest of the series, was cut; and at the same level the inflowing streams built their largest deltas. When overflow ceased and the lake was lowered by evaporation only, fainter shore lines were cut during pauses at lower levels.

The records of this lake as preserved in shore lines, especially in the Provo and Bonneville beaches, are particularly well shown along the Wasatch front and at the north end of the Oquirrh Range, in the form of sea cliffs, remarkably perfect cut and built terraces, beaches, and other shore features.

The Wasatch front also affords an excellent opportunity to study the forms of waste shed from the Wasatch Range into Lake Bonneville by water streams as seen to-day in deltas and fans, as well as the deposits formed by ice streams. It is generally believed that the maximum extension of the glaciers and the second high-water period of the extinct lake was essentially contemporaneous and that they correspond to the latest epoch (Würm, or Wisconsin) of the glacial period. It is important to remember in this connection that a long preglacial period of prevailing aridity is indicated by the manner in which the Bonneville shore lines cross the slopes of the large detrital fans that skirt the ranges uplifted less recently than the Wasatch.

Finally, abundant evidences of deformation along the Wasatch front marking the position of the Wasatch fault zone in post-Bonneville and postglacial time will be found in fault-stepped moraines and gullies transecting deltas.

ITINERARY

From the Utah State capitol grounds, at the head of the City Creek delta in Lake Bonneville, an excellent view embraces the principal features of the region, including the route of the trip along the Wasatch front.

West face of City Creek salient. (See fig. 7.) Along the west base of the Wasatch extends a north-south zone of hot sulphurous springs arising in places through cavernous openings in breccia. The west face of this spur, which extends 3 to 4 miles (4.8 to 6.4 kilometers) west from the frontal line of the main range, is made up of limestone of Mississippian age (Madison), which is capped with Eocene conglomerate. The steep limestone wall shows north-south fractures dipping steeply westward, is brecciated and slickensided, and in places bears cemented alluvium like that underlying the desert plain 40 feet (12 meters) below. It thus appears that "the steep western face

of this spur is a fault scarp" (31, p. 16). (See pl. 3, *A*.) The strike of the fault plane is N. 55° W., and the dip is 70°–74° SW. The latest slip between the spur and the alluvial plain amounted to 40 feet (12 meters).

Presumably the displacement of about 1,500 feet (457 meters) occurred intermittently, with intervals of no movement. A recent alluvial fan shows a scarp across its head, indicating beheading along the line of the Wasatch fault. North of this prominent salient a well-defined bight extends for about 12 miles (19 kilometers), and south of it another bight, intersected by City Creek Canyon, extends for some 5 miles (8 kilometers). According to Gilbert this salient represents a fault block dropped from the main range by the main fault, 3 to 4 miles (4.8 to 6.4 kilometers) east, and terminated on the west by parallel western members of the main Wasatch fault zone. According to the opinion that the Wasatch fault is a chain of crescentic faults, the City Creek salient marks the western junction of the two

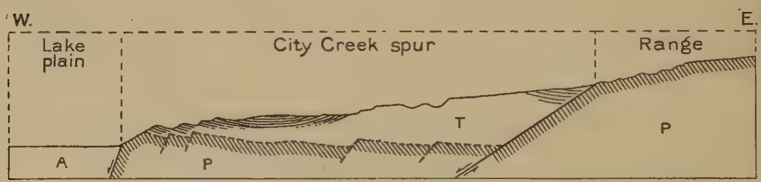

FIGURE 7.—Diagrammatic section of City Creek spur of Wasatch Range. A, Alluvium and lake beds of Jordan-Salt Lake Valley; T, Tertiary conglomerate and sandstone; P, pre-Cretaceous rocks, mainly Paleozoic. From U. S. Geol. Survey Prof. Paper 153, fig. 15, 1928

crescentic faults forming the 12-mile bight to the north and the 5-mile bight to the south.

Farther north along the fault zone, 4.2 miles (6.8 kilometers) from the capitol, a highway cut exposes buff shaly limestone that overlies Cambrian shale and corroded Cambrian limestone that underlies Ordovician (Swan Peak) quartzite. At Beck Hot Springs, 4.4 miles (7 kilometers) north of the capitol, at the foot of an exposure of Cambrian limestone, a hot spring rises at the intersection of two crescentic fault scarps.

Turning south and retracing the course past the capitol, the route follows south and east along Wasatch Boulevard, up City Creek, around the head of the City Creek delta, past an exposure of Eocene (Wasatch) conglomerate, volcanic tuffs, flows, and breccias of latite and andesite, and continues east along Wasatch Boulevard past the Veterans' Hospital and exposures of Wasatch conglomerate at the Mausoleum for 3½ miles (5.6 kilometers).

By a steep ascent on foot, 250 feet (76 meters) above the road, the level of the Bonneville terrace is gained, south of which the series of Bonneville lake beaches can be seen. From a knob of Eocene conglomerate, which here projects up through the Bonneville beach, there is a good view to the south, of the Wasatch front, the course of the fault scarp (31) or of interlocking crescentic scarps (28), the series of Lake Bonneville beaches, and the Wasatch piedmont slopes. To the northeast, 1½ miles (2.4 kilometers) away, may be seen Little Twin Peaks, of Madison limestone capped with Tertiary beds. Two miles (3.2 kilometers) to the north, in the upper City Creek Canyon, Cambrian shale and quartzite, lying in the path of the Wasatch fault of Gilbert, show an offset of only 800 feet (244 meters) down on the west, suggesting that the main fault lies farther to the west.

A third of a mile (0.5 kilometer) beyond, along the Wasatch Boulevard, at the mouth of Limekiln Gulch, good exposures show, from northwest to southeast, Mississippian Madison beds dipping south beneath Pennsylvanian Weber quartzite, which in turn passes, at Limekiln Gulch, under Park City limestone. The contact between the Weber and the Park City is exposed at the U; and the contact between the Park City formation and the overlying Triassic red beds (Woodside) appears beyond Dry Canyon.

The route leads up Dry Canyon to the Fort Douglas golf clubhouse. To the northeast Dry Canyon crosses the Weber quartzite and Park City formation and exposes along the trail up the canyon the unconformity between the Permian and the Triassic.

To the rear, above the Fort Douglas clubhouse and above the Bonneville bench, Cephalopod Gulch exposes the lower member of the Lower Triassic Thaynes formation (Pinecrest). The underlying Woodside shale, also Lower Triassic, is here about 1,000 feet (305 meters) thick and is capped at the rim of the south wall by the lower Thaynes (Pinecrest limestone). The best exposure of the Permian in the entire region is at the forks of Cephalopod Gulch, where it is 500 feet (152 meters) thick.

Farther up the left fork is a complete section of the Park City formation (Pennsylvanian and Permian), which is 566+ feet (173 meters) thick. The Permian and Pennsylvanian beds are here separated by a peculiar basal conglomerate, 72 feet (22 meters) thick. The following fossils have been obtained: Pennsylvanian part of Park City: *Orbiculoidea utahensis*, *Marginifera splendens*, *Chonetes* near *C. granulifera*, *Productus costatus*, *Hustedia mormoni*, *Spirifer cameratus*, and *Worthenia tabulata;* Permian part of Park City: *Ambocoelia arcuata*, *Composita mira*,

Lingula carbonaria, *Productus multistriatus*, *P. phosphaticus*, *P. subhorridus*, *Pustula montpelierensis*, *P. nevadensis*, *Spirifer pseudocameratus*, and *Spiriferina pulchra;* Woodside: *Myalina postcarbonica*, *Pleurophorus bregeri*, *P. rotundus*, *and P. similis?.*

The lower beds, containing the genus *Anasibirites* in abundance, are about 180 feet (55 meters) above the top of the Woodside. The fauna obtained from the Pinecrest strata has been correlated with the Lower Triassic faunas throughout the world and contains representatives of the *Meekoceras*, *Owenites*, *Anasibirites*, *Tirolites*, and *Columbites* intercontinental zones. The most widely known fossils are *Anasibirites kingianus*, *A. noetlingi*, *A. ibex*, *Columbites parisianus*, *Goniodiscus typus*, *Inyoites oweni*, *Kashmirites* near *K. subarmatus*, *Meekoceras gracilitatis*, *Nannites dieneri*, *Owenites koeni*, *Pseudosageceras intermontanum*, and *Aviculopecten weberensis.*

One mile (1.6 kilometers) to the south along Wasatch Boulevard the route passes through the Fort Douglas United States Military Reservation, located on the upper or inner side of the Provo lake terrace. The University of Utah, seen just west of the reservation, is lower down on the Provo terrace, at its outer side.

From the intersection of Wasatch Boulevard and Ninth Street South, looking east, an excellent general view may be gained of the synclinal structure of this portion of the Wasatch. (See fig. 5.) Forming the north limb of the major syncline, on the north side of Red Butte Canyon (the site of the type section of the "Permo-Carboniferous" of the Fortieth Parallel Survey), the Pinecrest formation, part of the lower Thaynes, with *Terebratula* bed showing prominently and with many minor faults, dips south beneath the Emigration formation, part of the upper Thaynes, and the overlying Ankareh formation in the bottom of Red Butte Canyon. South of the canyon the Ankareh (Triassic?) and the Nugget sandstone and Twin Creek limestone (Jurassic) continue on a south dip, beneath Emigration Canyon, which here marks the axis of the main trough. Beyond, to the south, the Twin Creek, Nugget, and Ankareh turn up on a northerly dip, forming the south limb of the main syncline. Between this point and Parleys the Emigration syncline, with its component members (Twin Creek, Nugget, and Ankareh), is duplicated in the subsidiary syncline as the second trough in the W.

Marking the top of the Triassic of this area the upper part of the Thaynes (Emigration formation) comprises 1,000 feet (305 meters) of calcareous sandstone intercalated with a few massive beds of resistant limestone, representing the shore phase of the retreating Lower Triassic sea. These beds have yielded the following fossils: *Astarte arenosa*, *Aviculopecten curtocardinalis*, *Dao-*

nella americana, *D. dubia*, *Monotis alta*, *Myalina permiana*, *M. platynotus*, *Pseudomonotis* sp., *Pugnoides uta*, *P. triassicus*, *Pentacrinus asteriscus*, and *Xenodiscus bittneri.*

The blood-red shale at the mouth of Red Butte Canyon is Ankareh, and the light-pink sandstone on the south wall of the canyon is Nugget, the resistant member crossing the canyon near the reservoir being the basal conglomerate of the Nugget. The Jurassic limestone (Twin Creek) is recognized by the light-gray color, dense, fine grain, and a fauna including *Astarte packardi.* Up Emigration Canyon an excellent exposure of the great unconformity between the Wasatch (Eocene) and pre-Tertiary formations can be seen, and at Kelvins Grove, 5 miles (8 kilometers) east of the front of the range, the base of the Cretaceous is exposed.

In this bight it is noticeable that the detrital slopes between the mountain spurs have larger volume and advance farther forward on the piedmont plain than they do farther south, where the mountains are higher; hence recent minor faulting would seem to have been weak or wanting here, but a number of very small faults, probably of earlier date, as they are not recognizable on the surface, have been found here in artificial cuts.

The name "Emigration Canyon" commemorates the fact that, in 1847, the original Mormon pioneers, under the leadership of Brigham Young, on their westward trek in search of a haven, descended this canyon and from its mouth obtained their first view of their promised land.

South of Emigration Canyon a benchlike salient occupied by a group of brick school buildings makes out from the base of the main range. On this bench ledges of Mesozoic rocks are found, equivalent to those in the spur ends behind them. Thus Jurassic and Triassic (Nugget and Ankareh) sandstones in the spurs apparently dip under or abut against down-faulted Jurassic limestone (Twin Creek) in the bench. Some interpret this bench as the top of a step-fault block which has not dropped enough to disappear; others as a surface marking retreat by erosion since faulting; and still others as a split in the Wasatch fault by which the mountain mass has been moved relatively north through a horizontal displacement of over 5,000 feet (1,524 meters).

From this point south the boulevard runs below the Bonneville terrace and above the Provo terrace, and between exposures on each side of the Ankareh, Nugget, and Twin Creek formations, overlain by Bonneville gravel.

Mouth of Parley Canyon. The view from the esplanade looking west embraces the Parley Canyon delta in the foreground, the City Creek salient at the north, the Traverse Mountain

salient at the south, and over the Jordan Valley the Oquirrh Range in the distance, with its piedmont slope, and to the north Great Salt Lake. To the east, on entering Parley Canyon, is a rock-walled gorge sharply cut by the issuing stream along the strike of Triassic rocks. Thus the Nugget sandstone forms the north wall and the Ankareh shale the south wall of the canyon; both stand nearly vertical and strike east. Resistant sandy members of the Ankareh show perfectly preserved ripple marks along the outside of the upper road and form prominent pinnacles beside the lower road at the reservoir.

Turning south from the Lincoln Highway down to the valley road the route leaves Parley Canyon and leads past the pinnacle of Ankareh sandstone at the reservoir, thence up over the delta of the Provo stage. In the next few miles along the base of the range a 4-mile (6.4-kilometer) bight is entered by Mill Creek and Neffs Canyon.

Between Parley Canyon and Mill Creek, dipping steeply north on the south rim of the major syncline, are seen the entire Triassic succession and the upper Carboniferous, including Permian and Pennsylvanian (Park City). Just south of Parleys a noticeable thin light-gray bed, the terebratuloid member observed earlier at Cephalopod Gulch, is seen to be folded complexly. Smooth spur-end facets are here well developed.

At the mouth of Mill Creek the upper Pennsylvanian part of the Park City formation forms the north wall and the lower Pennsylvanian Weber quartzite the south wall and the crest of the ridge below the gully next north, on Triassic shale (Woodside), and the canyon is occupied by the Permian part of the Park City formation. By a short climb to the Bonneville bench above the power house the scarp and shear zone of the main Wasatch fault, as described by Gilbert (31), can be clearly observed to the south.

Southward the road rises onto the Provo delta, whence a good view is obtained of the Paleozoic section, including the massive Pennsylvanian (Weber) quartzite, the Mississippian (Madison and Brazer limestones) unconformably below, followed conformably by the Devonian, the Ordovician (white, 300-foot (91-meter) Swan Peak quartzite) and the economically important Middle Cambrian Ophir limestone. Fossils found in Ophir shale in this vicinity include *Hyolithes billingsi*, *Lingulella ella*, *Micrometra* (*Iphidella*) *pannula*, *Zacanthoides typicalis*, and *Agnostus pisiformis*.

Next below is the Lower Cambrian light-pink Tintic quartzite, forming the north face of Mount Olympus. Continuing southward below the wave-cut Bonneville beach the route passes, on the east, Hughs Gulch, where the contact of the Lower Cambrian

A. WESTERN ESCARPMENT OF CITY CREEK SPUR, WASATCH RANGE

This is a fault scarp. The hanging valley is older than the fault. The face was washed by Lake Bonneville; the higher of the two conspicuous shore lines is the Provo. From U. S. Geol. Survey Prof. Paper 153, pl. 8, *A*, 1928.

B. FAULTS IN LITTLE COTTONWOOD MORAINE

The Pleistocene glacier protruded beyond the mouth of the canyon and built lateral moraines just outside. The scarp at the left, running up from the railroad cut, is relatively young and is scantily clothed with bushes; others at the right are older. From U. S. Geol. Survey Prof. Paper 153, pl. 13, *A*, 1928.

A. SCARPS AND GRABEN ALONG WASATCH FAULT

Shows flat-topped right lateral moraine of Little Cottonwood glacier. The principal piedmont scarp crossing it has a companion scarp facing toward the range, and between them is a graben. From U. S. Geol. Survey Prof. Paper 153, pl. 14, *B*, 1928.

B. SOUTH END OF MORGAN VALLEY, WASATCH RANGE

The smooth plain has been produced by alluvial deposition in a valley previously deep. From U. S. Geol. Survey Prof. Paper 153, pl. 26, *B*, 1928.

with the pre-Cambrian quartzite shows, and thence continues below pre-Cambrian ledges to Cottonwood Canyon. Along the portion of the Wasatch front between Mill Creek and the Cottonwood Canyons the control exerted on form of ránge front by rock resistance is clearly demonstrated. Thus the mountain front near Mill Creek Canyon, where most of the formations are resistant, is forth-standing, with strong facet-ended spurs, and the massive resistant quartzite of Mount Olympus forms a blunt cusp; but adjacent to Neffs Canyon, where the strata are weaker, well-rounded spurs retreat between indenting fans that overlap the fault line, and the fan heads at Mill Creek are still separated from the spur ends by the fault trace. Nowhere along this 25-mile (40-kilometer) segment of the Wasatch front are the overlapping fans better shown.

Again, just south of Neffs Canyon two ravine-fed fans afford evidence of the formation of landslides, both fans and slides being cut by the Bonneville shore line and thoroughly reworked along the Provo shore line after the Wasatch faulting and before Bonneville time.

Cottonwood Canyon. Eastward from the mouth of the canyon there is an excellent view of the pre-Cambrian section, 10,000 to 12,000 feet (3,050 to 3,650 meters) thick. The metamorphic rocks, chiefly quartzites and argillites, show along the range front; those on the north side are correlated with the pre-Cambrian Belt series, and those on the south, including chloritic and staurolitic schists, apparently older, may be equivalent to the older Cherry Creek series. The light-gray rocks on the south side are masses of Cottonwood granite intrusives. The terraces contouring around these formations at the mouth of the canyon are beach levels of Lake Bonneville. From the head of the Cottonwood delta extends a well-defined north-south gully or fosse, which marks the position of the Wasatch fault at this point and indicates recent movement beheading this delta.

Further signs of this movement are seen 9 miles (14.4 kilometers) south of Cottonwood Canyon in the shape of three distinct parallel faults traversing the delta in the general northerly course of the main Wasatch fault zone and including a dropped block.

Little Cottonwood Canyon. A view eastward from the mouth of this canyon, at the head of its delta, shows the deep narrow rock-walled canyon characteristically glaciated, with U cross section and polished walls. The high peaks near its head, over 11,000 feet (3,350 meters) above sea level, suggest the reason why, unlike the glacier in Cottonwood Canyon, the Little Cottonwood glacier extended out of the canyon. In recent time

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the mining town of Alta, at the head of Little Cottonwood Canyon, holds the country's record for deaths from snowslides.

The dark metamorphic rocks that prevail in this lower portion of the canyon are pre-Cambrian quartzites, argillites, schists, and gneisses, which are cut by extensive masses of light grayish-white granite. Both formations may be advantageously studied at a point 1½ miles (2.4 kilometers) up the canyon.

On the south side of the canyon mouth two well-preserved lateral moraines mark the positions of the Little Cottonwood and Bells glaciers. (See pl. 3, *B*.) Two breaks as steps in their crests show subsequent dislocation, for these faults in the front and back moraines are in exact alinement not only with each other but also with the well-developed fosse (pl. 4, *A*, foreground) which cuts across the head of this great Cottonwood delta, transverse to the course of the main canyon and in line with the range front (26). From the top of these moraines this displacement is seen to be not only downward on the west but also horizontal. Furthermore, these dislocations of moraines and delta deposits are also in line with similar breaks in glacial moraines to the south and in Bonneville beaches to the north, thus indicating the position of the underlying Wasatch fault and also late post-Bonneville and postglacial movement.

This Cottonwood delta, trending southwest and extending far out into the valley, is the most extensive in this region along the Wasatch front.

At the mouth of Bells Canyon, next south of Little Cottonwood Canyon, lateral moraines like those of the Little Cottonwood glacier were developed, and in addition a terminal moraine which ponds back the present stream.

Beyond to the south the range presents a regular, even front to a point about 20 miles (32 kilometers) south of Salt Lake City, where the Traverse Mountains project abruptly westward across the valley. The main range is here made up of Algonkian metamorphic rocks, which show well-developed faceted spur ends. The Wasatch fault is traceable along this section and was believed by Gilbert (31) to be marked by the groin at the head of the Traverse Mountain.

This transverse and lower range Gilbert regarded as a characteristic salient resulting from lagging of a downthrown block. The formations are now recognized as of Pennsylvanian age, equivalent to those prevailing to the west through the Bingham district. The predominant dip is northerly, off an east-west anticlinal axis which plunges west. Andesitic volcanic rocks overlying these sediments cap the spur. Well-developed lake terraces contour this transverse range on the north, and lake deposits form an extensive spit on the west.

The excursion will return to the city along the base of the range northward along the Jordan Valley, from which at successive points the geologic features observed at close range in following the Wasatch front southward may be reviewed at a distance.

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Excursion 2.—BINGHAM MINING DISTRICT

By Richard N. Hunt

LOCATION AND PRODUCTION

Bingham is 27 miles (43 kilometers) southwest of Salt Lake City. From the roof garden of the Hotel Utah on a clear day the uppermost benches of the Utah Copper operation at Bingham can be seen, about halfway south along the apparent length of the Oquirrh Range, just overtopping a ridge midway between the crest of the range and the valley floor.

The gross value of ores produced in Bingham since 1865 approximates $1,000,000,000. Of this sum the Utah Copper Co. has produced about one-half. The other half has been derived from subsurface mines which made Bingham an important camp before the inception of the Utah Copper operation and which still maintain it among the major lead and silver producing districts of the United States. Dividends paid by the mining companies of Bingham approximate $275,000,000.

ITINERARY

Seven miles (11 kilometers) from Salt Lake City on the right-hand side of the road to Bingham is the Murray lead smelter of the American Smelting & Refining Co. The bulk of the ore treated in this plant has come from Park City, a lead, silver, and zinc mining district in the Wasatch Range, due east of Murray.

On leaving the town of Midvale, 11 miles (18 kilometers) from Salt Lake City, the Bingham road passes between the flotation mill (on the left) and the lead smelter (on the right) of the United States Smelting, Refining & Mining Co. This company controls the largest subsurface operation in Bingham, the United States mine, which supplies the major portion of the Midvale tonnage. The Midvale mill has a daily capacity of 1,000 tons. It embodies the achievements of the past 15 years in the selective flotation and metallurgy of mixed sulphide ores.

A few hundred yards beyond the Midvale plant the road crosses a small stream, the Jordan River, which drains the valley between the Wasatch and Oquirrh Ranges. Rising in Utah Lake, a body of fresh water 20 miles (32 kilometers) to the south, it empties into Great Salt Lake some 10 miles (16 kilometers) northwest of Salt Lake City, where calcareous, oolitic sands are forming in a body of water totally devoid of the CO_2 radicle. The lime carbonate is attributed to organic agencies, as in the granules are found the forms of algae living within the freshening influence of the river water.

From the Jordan River the road ascends the long, even piedmont slope to the mouth of Bingham Canyon, where during recent years the Utah Copper Co. has built the town of Copperton. Residence here is limited to employees, who pay a reasonable rent adjusted to cover the company's investment in the community. Every building in the town is roofed with copper shingles.

Just beyond Copperton the road descends a small grade, and on the left appears the long, low building of the Utah Copper Co.'s copper-precipitation plant. This is a salvaging operation in which is recovered the copper in certain mine waters and in the run-off and seepage from large dumps of material of less than ore grade stripped from the Utah Copper ore body and deposited in gulches far enough from the pit to be out of the way of all future operations.

Formerly these waters were neglected, but now their content and volume are augmented by systematic diversion of water to these dumps, from which it is collected and conducted down the canyon in redwood pipes to the precipitation plant. Here

these waters yield 4,000,000 to 5,000,000 pounds (1,800,000 to 2,300,000 kilograms) of copper annually at a very low cost. This plant is capable of treating 8,000,000 gallons (30,000,000 liters) of water each 24 hours. The copper content varies greatly with the season and conditions at the source dumps, but averages about 10 pounds per 1,000 gallons (1.2 kilograms per 1,000 liters), of which approximately 9½ pounds is recovered. The precipitate, a reddish mud carrying more than 95 per cent (dry), is shipped directly to the Garfield copper smelter of the American Smelting & Refining Co.

From the precipitation plant the road ascends the canyon to become the principal and only street in a community of some 4,000 inhabitants till a branching in the canyon itself is reached. Here the road to the right passes up Carr Fork beneath a succession of railroad trestles of the Utah Copper Co. On the left or east side of Carr Fork are the switchback lines and grades by which the Utah Copper ore trains ascend and descend from the benches above the pit to the railroad yard above the town of Bingham. In the gulches on the right are many of the dumps of overburden, the waters from which are treated in the precipitation plant at Copperton. In Carr Fork are many of the subsurface operations—those of the Utah Apex Mining Co., the Utah Delaware Mining Co., the Utah Metal & Tunnel Co., and the Bingham Metals Mining Co.

The road following the main or easterly branch of Bingham Canyon ascends to the Utah Copper pit, the village of Copperfield, and the United States mine.

Whether or not the visitor's interests are technical, he will enjoy the view of the Utah Copper pit, either from its northerly edge near Copperfield or from the tracks upon the slope above and north of Copperfield. The entire pit is visible from these vantage points.

Unlike the open pits of the Mesabi iron range in Minnesota and other open-pit copper operations in the West, the Utah Copper pit is large in vertical dimension, which exceeds 1,500 feet (457 meters) and makes of the pit an enormous amphitheater. The benches, rising tier upon tier, present a vertical cross section of the ore body normal to its longer axis, which trends southwest, nearly coincident with the visitor's line of vision. The trains and shovels on the distant benches are of standard railroad gage; the cars have a capacity of 80 to 100 tons and the electric shovels a capacity of 4½ cubic yards (3.44 cubic meters). Receiving the ore directly from the shovels, these cars transport it 20 miles (32 kilometers) to the Magna and Arthur flotation mills, at the extreme north end of the

Oquirrh Range. These mills have a combined daily capacity of 50,000 tons. A record in production was obtained in April, 1929, when the daily average of ore removed from the pit and milled was 61,700 tons.

As the visitor may observe, the original surface was many hundreds of feet above the present benches, which from year to year steadily retreat in a southerly direction. Prior to January 1, 1931, 110,549,000 cubic yards (84,515,000 cubic meters) of overburden was removed to dump sites in near-by gulches; 204,-150,000 tons of ore was broken and milled, yielding 3,483,313,000 pounds (1,580,007,000 kilograms) of copper. Reserves of the same date were 640,000,000 tons of 1.07 per cent ore. Prior to 1932, $213,726,000 was distributed in dividends.

Encircling the Utah Copper property are the subsurface operations which for many decades have been large shippers of copper and mixed sulphide ores containing, principally, lead, silver, and zinc. These mines girdle the pit so closely that the Utah Copper Co. has been compelled to purchase extensive surface rights and dumping privileges from all of its neighbors. Its more than 100 miles (160 kilometers) of trackage are therefore spread over the greater part of the productive area, crossing and recrossing the sites of its neighbors' subsurface operations.

These subsurface mines exploit an interesting group of copper and lead-zinc sulphide ore bodies. For the most part these are replacement deposits in a succession of limestones near an intrusive monzonite in which the Utah Copper ore body largely lies.

Sulphide ore in substantial quantities has been mined throughout a vertical range of more than 3,000 feet (914 meters). Material which at former prices was considered of commercial grade extends below the lowest workings in all the productive areas. Of the mines of the district, the deepest on January 1, 1931, was the Utah Apex, which had then attained a depth of more than 1,900 feet (579 meters) below the bottom of the Utah Copper pit.

GEOLOGY OF BINGHAM

The Bingham mining district (pl. 5) lies upon the eastern slope of the Oquirrh Range, largely within Bingham Canyon and its principal tributary, Carr Fork. Most of the productive area lies within a circle with a radius of 1¼ miles (2 kilometers), described from the top of the Utah Copper hill, which rises 2,000 feet (610 meters) above these canyons and forms the divide between them. In the vicinity of the village of Lark, however, the productive area extends eastward to the edge of the Jordan Valley floor.

Bingham Canyon and Carr Fork traverse the upturned beds of a sedimentary series believed to be of Pennsylvanian age. In the productive area these sediments are warped into an open syncline plunging northwest. They consist largely of quartzite but include numerous calcareous strata which in their aggregate thickness form approximately one-third of the stratigraphic column. Several calcareous members, notably the thicker ones, are distinguished by names, because of their economic importance, and have been traced and explored throughout the district. Variously related to fissures and certain intrusive masses, but within these limestone members, have been found more than 90 per cent of the ores of the subsurface mines. (See figs. 8–11.)

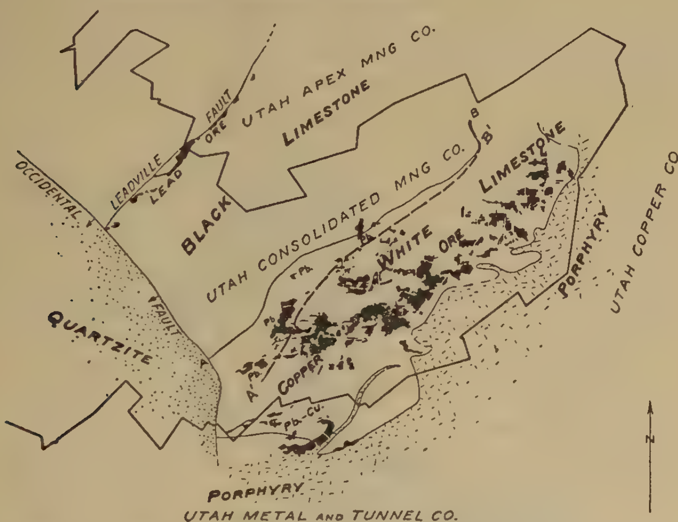


FIGURE 8.—Projection to horizontal plane of copper and lead stopes in Highland Boy limestone, Bingham district, showing position relative to one another and to the areas of altered white and unaltered black limestone and the porphyry mass of the Utah Copper stock. From Am. Inst. Min. Met. Eng. Trans., vol. 70, fig. 6, p. 873, 1924

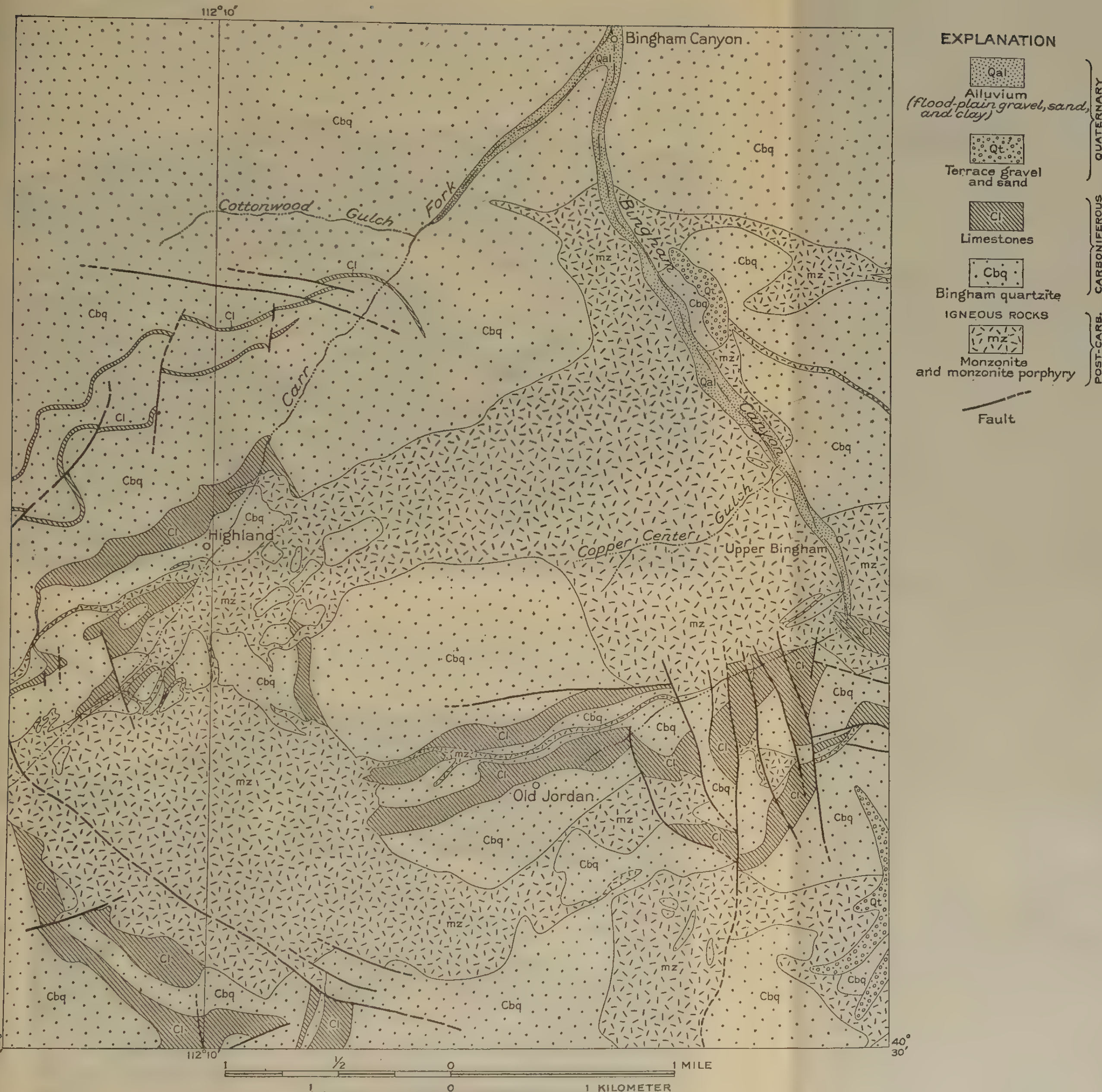
Because of the absence of Mesozoic sediments in the Oquirrh Range, post-Paleozoic events may be chronicled only by inference drawn from other regions. The synclinal structure of the district is attributed to orogenic movements at the end of the Cretaceous period. Degradation of the Paleozoic rocks concomitant with and following this folding was interrupted by the appearance of andesitic extrusives, believed to be of Tertiary age, which probably once covered the district. Subsequent movements that have produced the present topographic and structural units of the

region and possibly are still in progress appear to have rejuvenated the streams on the then existing surface, possibly by tilting it eastward. Erosion, thus stimulated, stripped the extrusive rocks from all parts save the extreme foot of the eastern slope of

FIGURE 9.—Vertical section northeast through copper replacement ore bodies in Highland Boy limestone, Bingham district, showing their confinement to that formation. From Am. Inst. Min. Met. Eng. Trans., vol. 70, fig. 7, p. 873, 1924

FIGURE 10.—Principal workings and stopes in Yampa limestone, Bingham district, projected to a horizontal plane, showing distribution of lead and copper ores in that limestone in relation to main mass of porphyry and to areas of altered white and unaltered black limestone. From Am. Inst. Min. Met. Eng. Trans., vol. 70, fig. 8, p. 875, 1924

the range, exposing in the underlying quartzite and limestones monzonitic intrusions which may have risen contemporaneously with the extrusives and to which the ore deposits of the district appear to bear a close genetic relation.



GEOLOGIC MAP OF CENTRAL PART OF BINGHAM MINING DISTRICT

Geology in part from map by R. N. Hunt (Am. Inst. Min. Eng. Trans., vol. 70, fig. 3, p. 861, 1924), supplemented by data from map by Arthur Keith and J. M. Boutwell (U. S. Geol. Survey Prof. Paper 38, pl. 1, 1905).

A

B

OUTCROP OF PORPHYRY ORE DEPOSITS OF UTAH COPPER CO. IN BINGHAM CANYON

A. View in 1908 when original outline of hill was still apparent. From U. S. Geol. Survey Prof. Paper 111, pl. 36, *A*, 1920. *B*. View in 1929. Photograph copyright by Cliff Bray Photos, Salt Lake City; used by permission.

Two irregular masses of monzonite are referred to as the Utah Copper and Last Chance stocks. Both range in mineralogy from diorite to quartz monzonite, they are generally similar petrographically, and the evidence indicates a common magmatic origin. They are connected by dikes and are thus a unit structurally. This fact seems noteworthy, because the spread of emanations that caused intense alteration of the limestones and deposition of the ores appears to have been radial with respect to the Utah Copper mass, whereas the Last Chance seems to have been comparatively inert.

Apart from impregnations of disseminated pyrite and infiltrations of quartz, intrusion induced little change in the quartzite. But the successive limestone members lost their normal gray to

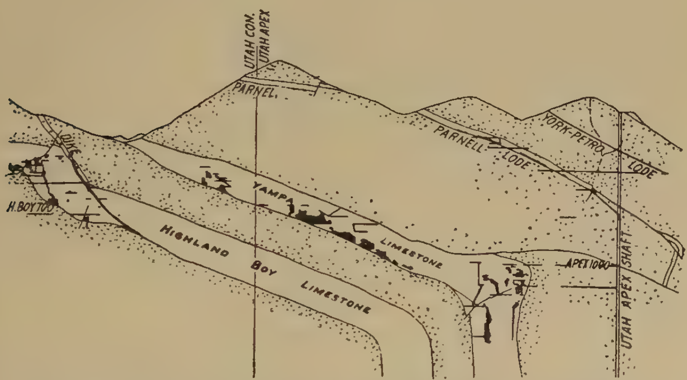


FIGURE 11.—North-south vertical section through the Highland Boy, Yampa, and Utah Apex mines, Bingham district, showing the productive limestone beds of the west side of the district. From Am. Inst. Min. Met. Eng. Trans., vol. 70, fig. 2, p. 860, 1924

black color in the vicinity of the Utah Copper stock and became reddish brown to snow-white, with the abundant development of garnet, diopside, wollastonite, and other lime silicates. The evidence is clear that existing structural features—bedding, joints, fissures, etc.—were important factors directing the mobile agents (aqueous, gaseous, or both) which effected or at least facilitated these alterations; and further, that the extent and degree of alteration, in general though not in detail, decrease in directions radial from the stock.

The evidence is inconclusive, but it is inferred that these alterations to some extent preceded the final incident of intrusion—the introduction of the sulphide ores of copper, lead, silver, and zinc. The distribution of the ores and mineralized rock in a great

corona, so to speak, enveloping the Utah Copper stock, and a certain mineralogic or zonal relation which they bear radially to it make the inference of a close genetic association of the ores with the intrusives inescapable. It may be added in support of this conclusion that these monzonite stocks and the ores are unique occurrences in the northern part of the Oquirrh Range, but that both appear again in close association at the southern extremity of the range in the old districts of Mercur and Ophir.

Possibly as a consequence of the relaxation of the intrusive forces, subsequent to the intrusion of the larger masses of the monzonite but prior to the cessation of the mineralizing process, normal northeasterly faults of small or moderate throw were formed at frequent intervals and became the sites of replacement ore bodies in the limestone members they intercepted. These fault fissures afford many excellent examples of the preferential replacement of the limestone members of the series to the exclusion of the intervening quartzite. There are numerous examples of the productivity of several successive beds of limestone where traversed by a northeasterly fissure; but rarely has minable ore extended through the quartzite intervals from one limestone bed to another along the fissure. The fissure may be mineralized with sulphides in the quartzite but usually is barren of commercial ore.

That a few northeasterly fissures have been invaded by small dikes of porphyry, even though the dikes may elsewhere displace masses of monzonite, indicates that they were formed before intrusive activity had entirely subsided.

Other premineral fissures, important in the localization of the ores, follow closely the stratification of the sediments. Many of them follow the footwall or the hanging wall of limestone members. Some of these so-called "bedding fissures" have been highly productive of both copper and lead-zinc ore, the same bed yielding copper ore in the immediate vicinity of the Utah Copper stock but lead ore at greater distances.

Other premineral faults strike northwest and dip west at very gentle angles. These antedate the monzonite and all known faults in contact with them. Their early age makes them obscure and difficult to trace; yet they have sufficient throw to introduce serious difficulties in the correlation of several of the productive limestones across the heart of the district. There is reason to suspect that they may antedate the folding.

Conspicuous gouges are common along both the northeasterly and the bedding fissures, which are accompanied by small postmineral shifts. But the latest structural features of consequence are northwesterly faults dipping west, which have a considerable throw and displace the monzonite, the northeasterly fissures, and the ore bodies. In some measure, at least, they are postmineral.

It is not impossible that these late fissures are synchronous with the recent faults of grand proportions described by Gilbert and others as factors in the uplift of the mountain blocks of the Great Basin region during the Tertiary and recent periods. The Oquirrh Range is held to be such a block, and its western slope to have been shortened by the scarp of such a northwestward-trending, westward-dipping Basin Range fault.

Structural features of some theoretical interest are irregular elliptical chimneys of breccia which appear in the south-central and eastern parts of the district. It is possibly an entirely fortuitous circumstance, but most of those now known lie near the northerly margin of the Last Chance stock and its easterly apophyses. The greatest dimension of these chimneys is vertical. Some are known to extend from depths exceeding 1,000 feet (305 meters) to the surface. They traverse all formations, obliterating and displacing them by their own mass, with irregular but sharp contacts, precisely like intrusive masses. The fragments represent all formations of the district, but those of monzonite and quartzite predominate. The matrix is either monzonite or fine fragmental material, some of which is stratified in the manner of débris filling cavities in limestone caves. Two widely separated chimneys are traversed by mineralized fissures and contain small ore bodies. These chimneys thus appear to be earlier than the last of the mineralization but later than much of the monzonite—an age relation which suggests close association with the intrusions, and possibly also with the extrusions if, as suggested, both phases of igneous activity were contemporaneous. It seems possible that these chimneys may prove to be a valuable link connecting both igneous processes in time, if not also genetically. It has been suggested that they are due to explosive forces. Their elliptical cross section and entire disregard of structural and formational lines of weakness suggest causal forces of so great magnitude as to render inconsequential any local differences in the resistance of structural features and materials. Such a force would be exerted in explosive action. Study of these chimneys may throw light on the mechanics of intrusion.

UTAH COPPER ORE BODY

The Utah Copper ore body (pl. 6) consists of a great nebula of disseminated pyrite and lesser proportions of copper sulphides diffused through the mass of variably silicified and silicated monzonite, quartzite, and limestone. Its greater dimensions are parallel with the northerly contact of the Utah Copper stock, in which it largely lies. It passes beyond the margin of the stock, however, into areas of quartzite and limestone. The longer axis of the ore

body measures 5,600 feet (1,707 meters) in the direction N. 45° E., one end passing beneath Bingham Canyon. The maximum width normal to this axis is 3,600 feet (1,097 meters). The deepest developed ore, 1,000 feet (305 meters) below the bottom of the pit, is more than 2,000 feet (610 meters) below the uppermost benches in ore. Beneath a relatively thin capping 100 feet (30 meters), more or less, in thickness, from which the copper has been partly leached, the average grade of the ore is slightly more than 1 per cent. Of the total copper 95 per cent is in sulphide form. In average ore the principal copper minerals and proportions of each are as follows: Chalcopyrite 80 per cent, chalcocite 9 per cent, covellite 7 per cent, bornite 4 per cent. Though constituting only a small percentage of the ore, pyrite is the most abundant and conspicuous sulphide. The gangue consists of introduced silica and the silicates of the monzonite.

The copper content in ground within 100 feet (30 meters) of the lower limits of oxidation is in places erratic and high. The change from capping to sulphide ore is often marked by a few feet of exceptional value. But grade variations in the Utah Copper ore body smooth out rapidly at greater depths and become only such as are characteristic of areas of disseminated sulphides at depth in many parts of the district. The grade and mineralogy of the ore developed at great depth during the past decade are not essentially different from those of the ore mined at higher levels. The bulk of the copper is in the form of chalcopyrite. The burden of proof would rest heavily upon one who would hold that the Utah Copper ore body as a whole, however much it may have been affected by secondary processes in its upper parts, is other than hypogene in its origin and character. In this it differs in no way from the bulk of the ores exploited in the subsurface mines.

ZONAL DISTRIBUTION OF COPPER AND LEAD-ZINC ORES IN THE LIMESTONE MEMBERS

An interesting aspect of the sulphide ores formed by replacement in the limestones is the manner in which they cluster about the Utah Copper stock and its apophyses, and the changes in their mineralogy in directions radial with respect to the stock. In these relations the ores reflect the somewhat similar distribution of alterations in the limestones. But the extent of the ores outward from the stock is greater than that of the contact alterations, with the result that lead ores are mined in black unaltered limestone for long distances beyond the silicated areas. These changes in the mineralogy of the ores result in a rudely concentric, zonal distribution—the purely copper ores occupying

an interior zone within the stock and extending some hundreds of feet from it in the most highly altered areas in the limestones; the lead and zinc ores predominating in a more outlying belt; and, weakly developed on the south side of the district, an outer zone of siliceous silver ores with variable proportions of base-metal sulphides.

These belts are not mutually exclusive, for fissures bearing lead ore appear in the copper-producing areas and, as erratics, even in the Utah Copper ore body itself. But copper ores free from lead and zinc are not found in the outlying areas, from which has come the bulk of the lead-zinc production of the district. These relations are best developed on the west side of the district, where at four successive horizons may be observed the transition from the inner dominantly cupriferous area to the outer lead-bearing belt. On the south and east these broad relations still exist; but the inner zone has been less productive of copper and is characterized by the development of pyrite and locally of specularite, with only a little copper and with lead and zinc lacking or occurring only erratically.

Though these changes are more striking in the horizontal distribution of the ores, they appear also in the vertical plane in certain ore shoots.

The repetition of these cycles of change in the ores and in the alteration of the limestones at several separate horizons and in opposite directions upon opposite sides of the stock makes it unusually clear that the source of the emanations effecting the changes was somewhere within or beneath the area of this central intrusive mass, the Utah Copper stock. The Last Chance stock has no such girdle of ore bodies and spread of alteration in the limestones surrounding it. Such ore bodies as have been found near it are properly regarded as occurrences within the influence of emanations originating in the area of the Utah Copper stock. If, as has been suggested in some other districts, the intrusive masses themselves were potent sources of heat setting up convection currents in the ground waters of the area, and these waters by some curious process of leaching and redeposition abstracted the metallic ingredients of the ores from the mass of the stock itself and concentrated them in the compact form of ore bodies, the Last Chance stock might be expected to have such an aureole of mineralization. But it seems simpler to assume that among the final incidents of intrusion was the upwelling and ejection of juvenile solutions infinitely smaller in mass than the magmatic body itself and therefore incapable of bathing and affecting more than a fraction of the area surrounding the intrusive body. That one portion of the intrusive

rather than another should coincide with the area containing or should itself contain the principal vents of such emanations, may be largely a fortuitous matter.

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Excursion 3.—STRATIGRAPHY OF THE CENTRAL WASATCH AND WESTERN UINTA MOUNTAINS

By John M. Boutwell [6]

The excursion in the Wasatch and Uinta Mountains offers primarily stratigraphic features and secondarily structural features. Two traverses are made completely across the Wasatch Range separated by a distance of 35 miles (56 kilometers); traverses are made across the Uinta Range at its west end, across the area lying between the two ranges, and along 35 miles of the west base of the Wasatch. The stratigraphy, structure, and geologic relationship of these ranges are thus observed. (See pl. 1.)

From Salt Lake City the route leads southeastward to Parley Canyon, thence eastward up the canyon through the Wasatch Range to Kimballs, southward along the east base of the range

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[6] In the preparation of this section the author has utilized notes furnished by Prof. A. A. L. Mathews, information by Mr. R. E. Redden, and writings of various geologists.

to Hailstone, eastward across the valley fill to the Uinta Mountains, northward across the west end of that range from Provo Valley to Weber Valley, northward down the Weber Valley across a Tertiary basin to Croyden, northwestward down Weber Canyon across the Wasatch Range to Salt Lake Valley at Uinta and Ogden, and southward along the west base of the Wasatch to Salt Lake City.

GENERAL GEOLOGY

This area contains two major structural axes—the north-south Wasatch folds and the east-west Uinta arch. (See pls. 1, 2.) In the angles between these folds, east of the Wasatch Range, are two great synclinal basins—the Uinta Basin, south of the Uinta Mountains, and an unnamed basin north of that range. The rocks involved in the Wasatch and Uinta folds are sediments ranging from pre-Cambrian to Jurassic; the intervening Uinta and Coalville Basins are floored with Tertiary beds, beneath which, around the margins and in some deeply incised canyons, Cretaceous rocks appear. Topographically, the low-lying interior plain of the Salt Lake Desert, 4,340 feet (1,323 meters) above sea level, is walled in on the east by the lofty north-south Wasatch Range (altitude 10,000 to 12,000 feet, or 3,050 to 3,660 meters), from which stretches eastward the great high-lying Utah-Colorado plateau (altitude 6,000 to 7,000 feet, or 1,830 to 2,130 meters), open along the Uinta axis by that arch, rising to a general altitude 2,000 to 3,000 feet (610 to 914 meters) higher. The Wasatch Range is drained westward through narrow, steep-sided, steeply graded canyons to the Great Salt Lake Basin; the Uinta and Coalville Basins eastward into the Green River and thus northwestward into the Bear River. Between the two, from the northwestern and southwestern parts of the Uinta Mountains, the Weber and Provo Rivers, respectively, flow northwest and southeast through the Wasatch Range.

The route passes through the Wasatch Range, following the synclinal structure that marks the westward extension of the north side of the Uinta Basin; crosses the filling of andesitic flows and agglomerates that occupy the area in which the Wasatch and Uinta Ranges unite and the low divide between the upper Provo and upper Weber drainage basins; crosses the arch of Paleozoic and Mesozoic sediments composing the Uinta arch; passes across the extensive well-exposed section of Tertiary and Cretaceous formations in the Coalville Basin; descends westward through exceptional exposures of Jurassic, Triassic, Carboniferous, and pre-Cambrian rocks; and returns southward along the west base of the Wasatch Range beneath Bonneville terraces and east of Great Salt Lake.

ITINERARY

From the Eagle Gate, Salt Lake City (altitude 4,340 feet, or 1,323 meters), the route leads southeastward toward the mountains, ascending gradually across the alluvial apron and lower Bonneville terraces that blanket the base of the Wasatch Range. To the east is a good general view of the broad synclinal structure of the Wasatch in Permian, Triassic, and Jurassic sediments. (See fig. 5.)

Mouth of Parley Canyon, 8.7 miles (14 kilometers) from Salt Lake City. From the lookout good views may be obtained of the Wasatch front to the north and south, the City Creek and Traverse Mountains salients, the Jordan Valley, the Oquirrh Range, and Great Salt Lake. At the entrance to the canyon Jurassic (Twin Creek) limestone of steep northerly dip overlies unconformably Jurassic (Nugget) ripple-marked sandstone and red shale. On the south side of the canyon the resistant basal portion of the Jurassic (Nugget) sandstone overlies the Triassic (?) (Ankareh) red shale and stands on edge to form a prominent wall.

On the north side of the canyon, 1.1 miles (1.8 kilometers) farther on, the highway cuts up across the base of the Jurassic (Twin Creek) limestone. Half a mile (0.8 kilometer) beyond is a quarry in limestone (Twin Creek) used in cement manufacture. The highway at this point on both sides is in Twin Creek limestone and for the next 4 miles (6.4 kilometers) exposes the entire Twin Creek formation, showing argillaceous limestone near the base, grading upward into shaly limestone and, near the top, shale. This formation has been traced to the type section along Twin Creek, in southwestern Wyoming. Its fauna includes *Astarte packardi*, *Camptonectes bellistriatus*, *C. stygius*, *Lima occidentalis*, *Ostrea strigilecula*, *Pleuromya weberensis*, *Pena kingli*, *Trigonia montanaensis*, *T. quadrangularis*, *Nerinella stantoni*, and *Macrocephalites* aff. *M. macrocephalus*. Upward the Twin Creek passes without break into upper Jurassic (?) (Morrison) red beds.

At 14.3 miles (23 kilometers), on the north side of the highway, the Mountain Bell Reservoir of the Salt Lake City domestic water system occupies a valley in Jurassic (?) (Morrison) sandstone and shale. On the crest of the first hill east of the reservoir steeply dipping Morrison is overlain by nearly horizontal coarse basal conglomerate of Cretaceous age (Kelvin), making an angular unconformity of 60°. The route eastward from the reservoir follows the Morrison, with the basal Cretaceous (Kelvin) showing to the north. As no Cretaceous has been described west of this point to the Great Basin region, this conglomerate is regarded as marking the western shore of the great Cretaceous sea.

South of the fill 3.1 miles (5 kilometers) beyond the reservoir is Lambs Canyon, in Jurassic (?) (Morrison) shale, and nearly horizontal Tertiary beds form the top of Big Mountain (altitude 8,282 feet, or 2,524 meters). Thence eastward the highway follows the Morrison formation to the summit.

At 20 miles (32 kilometers) the highway crosses the main divide of the Wasatch by Altus Pass (altitude 7,043 feet, or 2,147 meters). The pass is in maroon shale and sandstone of Morrison age. The ridge north of the pass is made up of the basal member of the Cretaceous, and the mountain above is capped by andesite.

The descent of the eastern slope of the Wasatch by a wide flaring valley leads by a gentle grade to inside uplands and meadows, in sharp contrast with the youthful character of the dissection of the western slope of the range. The ridge to the south shows Jurassic (Nugget) with discordant strikes and Morrison and Twin Creek abnormally present, indicating an overthrust fault.

At Kimballs (altitude 6,366 feet, or 1,940 meters), 25 miles (40 kilometers) from Salt Lake City, the route turns southeast from the Lincoln Highway toward the Park City mining district. The valley opens eastward into the broad rectangular meadow, 3 miles (4.8 kilometers) north and south by 2 miles (3.2 kilometers) east and west, known as Parleys Park, the first of several of these characteristic inner valleys to be seen on this excursion. These have been explained variously; Gilbert (54)[7] has held them to mark fault blocks dropped along the east base of the Wasatch. In the vicinity of Kimballs Jurassic (Nugget) sandstone over Ankareh forms the ridge to the north, capped by Jurassic (Twin Creek) limestone, and also continues south, indicating local doming. On entering Snyderville, 2 miles (3.2 kilometers) from Kimballs, Beckwith sandstone can be seen overlying Jurassic (Nugget) sandstone, and fossiliferous limestone (Twin Creek) forming the ridge to the south. Two miles farther on the highway passes through a gap in Jurassic (Nugget) sandstone overlying Ankareh shale.

At the outskirts of Park City, 30½ miles (49 kilometers) from Salt Lake City, the route crosses the north end of the Park City anticline, made up of the Carboniferous and Triassic formations that contain bonanza bodies of silver, lead, copper, and zinc ore. The ridges rising to the south are made up of the Jurassic (Nugget) and Lower Triassic (Thaynes) dipping northwest on the western limb of the anticline; and those to the southeast of the Carboniferous dipping east from the eastern limb. To the south

[7] Numbers in parentheses refer to bibliography, pp. 68–69.

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Thaynes Canyon, ascending southward with ice-cut profile, heads in Jupiter Hill (altitude 10,007 feet, or 3,050 meters), which is formed of argillite metamorphosed from Triassic shale. Several springs near by are all brought to the surface by shale members. Just beyond to the south the highway again forks; the economic geologists intending to visit the mines will take the west branch and continue on to Park City (see pp. 69–81); the stratigraphers intending to visit the Mesozoic and Tertiary sections will take the east branch and, passing north of Park City, continue eastward.

The eastern route follows the valley on Lower Triassic (Woodside) shale. The low mound to the north of the cemetery is on overlying Lower Triassic (Thaynes) limestone. Two miles (3.2 kilometers) beyond the fork the road passes out of the strike valley by a dugway cut in Triassic red shale; Carboniferous limestone (Park City) forms the south side of the valley.

The route then enters a series of andesitic flows and agglomerates, which here bury the northeastern portion of the Park City anticline, and passes gray deposits on both sides composed of tailings from concentration mills working on ores in the canyons above.

The view looking west shows a portion of the Park City mining district and in the distant background Clayton Peak (altitude 10,728 feet, or 3,270 meters), formed by an extensive stock of diorite. The diorite cuts and metamorphoses sediments adjoining on the north, such as the argillite composing Jupiter Hill, which are traversed by master northeasterly fissures carrying extensive veins of valuable silver-lead ore—for example, the Crescent vein, on Crescent Ridge, which faults the Jurassic down 1,000 feet (305) meters) against the Triassic. In the near foreground is a ridge marking a major overthrust fault, overriding two formations; and in the immediate foreground the mouth of the Ontario drain tunnel, 3 miles (4.8 kilometers) in length. The Ontario mine produced between 1872 and 1896 silver-lead ores that yielded over $60,000,000 worth of silver. Near by is the plant of the Park Utah Consolidated Mining Co.

A mile (1.6 kilometers) beyond Keetley post office, on the east, the route passes prospect workings of the Premier Mining Co. Half a mile (0.8 kilometer) farther on it leaves the highway and turns east up the Provo River. For the next 6 miles (9.6 kilometers) it follows the gorge cut by the Provo in a series of andesitic flows and agglomerates, revealing the nature of the filling of the valley between the Wasatch and Uinta Ranges. An excellent exposure of the flat-lying andesitic series crosses the canal used for diverting drainage from the Weber to the Provo system.

A deep gravel fill exposed along a canal cut now separates the Weber and Provo River systems. The low, flat divide seen to the northeast raises a query as to the original course of these two major streams, which flow west out of the Uinta Mountains along the strike, are here separated by the low gravel divide, and thence pass westward through the Wasatch Range. These facts suggest beheading of the original Weber River by the Provo (54, p. 56). The view looking east shows the west end of the Uinta arch, whose southward-dipping flank exhibits Carboniferous formations (Weber and Park City) opened along their strike by the wide valley of the Provo River: also Rhodes Valley, at the west base of the Uinta Mountains, possibly occupying a dropped fault block (54).

Descending to Rhodes Valley and continuing northward along the west base of the Uinta Mountains across a low, undulating divide at 52 miles (84 kilometers) from Salt Lake City, the route passes through the Mormon agricultural settlement of Kamas (altitude 6,482 feet, or 1,967 meters; population in 1930, 491).

East of Kamas, up Beaver Creek, limestone outcrops at the roadside afford a Lower Carboniferous fauna (early Mississippian or Madison) and mark the lowest formation exposed in the western Uinta Mountains. This fauna includes a coral (*Menophyllum*) 6 to 8 inches (15 to 20 centimeters) long, *Spirifer centronatus*, *Productus*, and two trilobites (*Phillipsia*).

Continuing north 2½ miles (4 kilometers) beyond Kamas, the route crosses the main east-west axis of the Uinta Mountains. The formation cropping out to the east is the Weber quartzite, dipping to the south and north on the two sides of the axis and overlying Madison limestone with shale of possibly still earlier age.

A detour up the Weber River shows a view northeast up the canyon cut into Jurassic (Nugget), Triassic (?) (Ankareh), and Lower Triassic (Thaynes and Woodside), forming the north wall, and Permian and Pennsylvanian (Park City) and underlying Pennsylvanian (Weber), forming the south wall. The road up the canyon cuts, at 1½ miles (2.4 kilometers), the middle red shale of the Thaynes; half a mile (0.8 kilometer) beyond, the upper half of the Thaynes; half a mile farther, the Ankareh on the north side of the canyon and the Thaynes on the south side; at another half mile the Nugget sandstone; and 1.8 miles (2.9 kilometers) farther, the Twin Creek limestone. Just beyond, at the point where a creek enters from the north, the relations of the formations seem to indicate that the Twin Creek limestone has been thrust eastward along the northeast overthrust fault, burying Cretaceous (Beckwith and Aspen) subsequent to the

elevation of the Uinta Mountains. The low hills north of the canyon are capped by andesite.

From Oakley (altitude 6,526 feet, or 1,989 meters) the route crosses andesite for 3 miles (4.8 kilometers) to Peoa (altitude 6,200 feet, or 1,890 meters), situated on the east side of Weber Valley, where Nugget sandstone, surrounded by andesite, dips southwest. Leaving the Uinta Mountains near Peoa and descending the Weber Valley, the route leads northwestward across a basin of Tertiary sediments. At 0.8 mile (1.3 kilometers), north of Peoa, near a spring on the east side of the road, Jurassic (Nugget) sandstone dips steeply northwest, and 1.1 miles (1.8 kilometers) beyond Peoa the route crosses the base of the Jurassic (Twin Creek limestone) and passes cliffs on the east of Upper Jurassic (?) (Morrison, Beckwith) carrying in the maroon portion cupriferous seams and in other portions gastroliths.

Beyond the maroon Jurassic (?) the road cuts through a prominent conglomerate, which overlies unconformably the Jurassic and marks the base of the lowest Cretaceous (Kelvin) formation. This basal conglomerate is made up of well-rounded pebbles of chert 1 to 6 inches (2.5 to 15 centimeters) in diameter, and passes upward into greenish calcareous sandstone and reddish nodular calcareous shale. The general strike is N. 55° E. and the dip 70° NW.

Beyond the road cut the slopes on the east expose Lower Cretaceous (Colorado), 7,500 feet (2,286 meters); the overlying Aspen, carrying fish scales; and sandstone forming the base of the Spring Canyon coal succession. Half a mile (0.8 kilometer) beyond is the overlying Frontier sandstone (58).

The route crosses the Weber River and turns north into the town of Rockport (altitude 6,019 feet, or 1,835 meters). The view east up Crandall Canyon shows Upper Cretaceous buff sandstone (Frontier) and red sandstone (Morrison) where an overthrust from the northwest, striking northeast, buries the formations (Frontier down to Twin Creek). The red Morrison beds here carry innumerable small seams of cupriferous pyrite yielding a little silver.

In the next 4 miles (6.4 kilometers) the route traverses Cretaceous sediments, including red Morrison, Beckwith, Kelvin conglomerate, Longwall sandstone, and Aspen shale, and passes tunnels driven into the Colorado for coal seams occurring in the lower portion of the Frontier.

At Wanship (altitude 5,871 feet, or 1,789 meters), where the route reunites with the Lincoln Highway, it encounters on the west andesitic conglomerate and lava which form the north end of the extensive series filling the valley between the Uinta and

Wasatch Mountains, observed along the Provo River. At this point the route crosses the railroad and the bridge over the Weber River.

In the distance at the left Lewis Peak (altitude 9,319 feet, or 2,840 meters) may be seen. On the ridge at the right can be seen the Kelvin with unconformity, Dome Mountain on the north made up of Tertiary rocks, and on the north slope Tertiary unconformably overlying Cretaceous (Colorado).

As the route enters Hoytsville Tertiary beds appear on the east; on the west is Cretaceous capping the ridge and unconformably underlying the Eocene (Wasatch). On leaving the town, Cretaceous is seen on the east, and 1 mile (1.6 kilometers) beyond, on a knoll at the east, a syncline is formed by Tertiary beds dipping south into the Cretaceous, which dips north. Here the route crosses the top of the Cretaceous (Colorado). Thence for 1½ miles (2.4 kilometers) the highway to Coalville is in Cretaceous, and to the west can be seen the "Laramie," Frontier, Hilliard, Adaville, and Evanston.

At the junction of the Weber River with Chalk Creek is the town of Coalville (62), the oldest coal-mining town in Utah, where high-grade subbituminous coal has been mined for over 50 years. The stratigraphic section exposed in the vicinity of Coalville comprises 9,000 feet (2,743 meters) of sediments of Upper Cretaceous (Colorado) age, chiefly the Hilliard and Frontier formations. Characteristic fossils found are *Inoceramus labiatus*, *Tellina modesta*, *Cardium pauperculum*, *Glauconia coalvillensis*, *Ostrea soleniscus*, *Corbula nematophora*, *Fasciolaria? utahensis*, *Mactra utahensis*, and *Barbatia micronema*. These beds were folded into an overturned anticline and highly faulted in two periods—the more intense faulting after the deposition of the topmost Cretaceous and before the deposition of the Wasatch conglomerate, and the lesser after the deposition of the Wasatch. The coal is found in three seams—the "Wasatch" (the principal one), "Dry Hollow," and "Spring Canyon." The "Wasatch" bed, averaging 9 to 14 feet (2.7 to 4.3 meters) in thickness, overlain by sandstone and in places by shale and underlain by shale and sandstone, has been mined extensively throughout its extent beneath the town of Coalville. At Chalk Creek Cretaceous (Frontier) sandstone crops out. At the northern edge of the town is the conglomerate marking the top of the Colorado and the bottom of the Montana, and just beyond are fossiliferous sandstone beds in the Hilliard formation.

The Echo Reservoir soon becomes visible to the northwest, and 1½ miles (2.4 kilometers) below Coalville the route crosses Grass Creek, with coal mines to the east. Shaly limestone of Upper Cretaceous age, overlain by Montana and later beds, here

contains abundant pelecypods. North of Grass Creek, Montana beds (Hilliard and Adaville), showing marked changes in lithology and fauna, appear.

A mile (1.6 kilometers) beyond, on the east, is an unconformity between Upper Cretaceous and Tertiary; and just beyond the viaduct and railroad Tertiary comes in and may be seen outcropping on all sides of the reservoir. Beyond the dam of the Echo Reservoir the route descends under a railroad trestle and unites in Echo Canyon with the road from the east. Thence west to the town of Echo (altitude 5,776 feet, or 1,760 meters) coarse cliffs of reddish conglomerate overlook the road. This conglomerate is Tertiary (Wasatch), the Vermilion Creek Eocene of early surveys and then regarded as lake deposits but more recently as continental deposits. An excellent example is seen in Pulpit Rock, at the junction of Echo and Weber Canyons. This conglomerate becomes thicker, more massive, more resistant, and coarser at the west, where it overlies all older formations unconformably, forming the capping of some of the higher mountains. To the south and west of Echo the conglomerate dips to the east, in part on an initial dip slope. Farther down the canyon the formation is folded in general conformity to late Tertiary structure. This Tertiary conglomerate almost completely conceals the unconformably underlying Cretaceous beds. About 2½ miles (4 kilometers) below Echo is a dome in the Tertiary, and springs are brought to the surface along the plane of unconformity.

Half a mile (0.8 kilometer) beyond the town of Henefer are towering cliffs of Wasatch conglomerate containing limestone pebbles, dipping east.

The Tertiary (Wasatch) conglomerate with many limestone pebbles, to the south, rests unconformably upon the Twin Creek, Beckwith, and Aspen, to the north. The Twin Creek appears on both sides of the road and dips steeply north.

From Croyden to Morgan the Weber River has cut a canyon roughly transverse to the formations and thus exposed on each wall in exceptional completeness and clearness the Jurassic, Triassic, and Carboniferous (Permian, Pennsylvanian, and Mississippian) beds. The section along a transverse ridge on the north side of Cottonwood Canyon constitutes the type section of the middle Wasatch (50, 52, 55).

In general, along the route of this excursion in Weber Canyon, the calcareous and argillaceous formations make prominent spurs and ridges, and the intervening shaly nonresistant formations make valleys.

At Croyden, on Lost Creek, the Jurassic and Triassic crop out from beneath the Tertiary, and Jurassic limestone (Twin Creek) is quarried and utilized for the manufacture of Portland cement. The road continues down the canyon across the railroad track and one-third of a mile (0.5 kilometer) below Croyden, on the west side of the canyon, passes the famous Devils Slide, formed through differential erosion of resistant members of the Twin Creek limestone between shaly nonresistant members. At 500 feet (152 meters) below the Jurassic Twin Creek, the underlying Jurassic Nugget appears on both sides of the canyon as cliffs of red sandstone. Owing to dust from the gray Twin Creek limestone ground at the cement works, the surface of this red sandstone locally appears of whitish-gray color. In and across the next gulch north, Triassic (?) (Ankareh) shale and sandstone stand nearly vertical. On the west side of the gully the Lower Triassic (upper Thaynes, Emigration) crops out as flaggy limestone dipping east, and the resistant limestone of the lower Thaynes (Pinecrest), containing metamorphosed cephalopods, forms the succeeding spur. The adjoining gully is eroded in Lower Triassic (Woodside) red shale.

Underlying and forming the next spur is Carboniferous (Park City) limestone carrying a characteristic Permian and Pennsylvanian fauna, including *Spiriferina pulchra* and *Pustula montpelierensis*. On a protruding spur the Park City limestone is underlain, with slight angular discordance (50), by massive Weber quartzite (also Pennsylvanian), which is absent 15 miles (24 kilometers) to the north.

Next beyond is the type section of the Weber for the early geologists. The river here swings in a wide crescent cut in the quartzite, which is folded and faulted, its actual thickness being thus seriously obscured.

The canyon opens into Round Valley, with the Weber forming the north wall for 2 miles (3.2 kilometers) and then giving way beneath to reddish ledges of dark limestone dipping east. This underlying limestone formation, marking the north wall for 1½ miles (2.4 kilometers), made up of blue-gray limestone (Morgan) with black chert, carries brachiopods and is described as Pennsylvanian (50). An unconformity separates it from the underlying Mississippian. The Morgan here yields *Productus cora*, *Pustula nebraskensis*, *Spirifer cameratus?*, *Spirifer rockymontanus*, *Composita subtilita*, and *Hustedia mormoni*.

The town of Morgan (pl. 4, *B*) is situated in a wide, open valley just east and inside of the main Wasatch Range, similar to Parleys Park, to the south, and described as a graben (54). The slopes to the east are Pennsylvanian (Morgan) limestone; to the

south and west the Wasatch unconformably overlies the limestone; and at the southwest the valley is cut in pre-Cambrian rocks. Pliocene lake beds have been found in Morgan Valley (54). Below Morgan the Weber River cuts deeply into a heavy gravel filling, exposing at points to the north gray limestone of Madison age, dipping east. Contouring around the west side and the outlet of the valley are well-defined terraces. These are associated with Bonneville beaches on the west side of the Wasatch Range and are regarded as formed by an eastern arm of Lake Bonneville extending up Weber Valley and spreading out in Morgan Valley as an inner lake (54).

The town of Peterson, 10 miles (16 kilometers) beyond Morgan, is located on rocks of Tertiary age. Below, to the north, is pre-Cambrian pegmatite beneath the Tertiary; and beyond, Quaternary deposits of the Bonneville epoch blanket pre-Cambrian metamorphic rocks, including mica schists and gneisses, which here form the core of the range.

At 13 miles (21 kilometers) from Peterson is the Weber station of the Utah Power & Light Co. Beyond, Quaternary gravel appears; and 2½ miles (4 kilometers) beyond, the route passes out of the mouth of the valley to the head of the Weber delta, which extends westward for several miles into the Bonneville area. (See pl. 7, *B*.) A fosse across the head of the delta marks the underlying Wasatch fault zone, which is traceable for many miles along the west base of the Wasatch Range; thence the highway swings to the northwest and in a distance of 5 miles (8 kilometers) reaches Ogden.

Ogden is several miles west of the Wasatch scarp, northwest of the point where the Weber River emerges from the range. Northeast of Ogden the Wasatch is deeply incised by the canyon of the Ogden River, which shows a fine section of gray Cambrian and Mississippian limestone on both sides of the canyon. Several miles up from its mouth is a remarkable series of flowing wells, which afford the domestic water supply for the city of Ogden. They have been the subject of much geologic and legal controversy as to their source and ownership.

On the mountain front north of Weber Canyon, 3.4 miles (5.5 kilometers) from Ogden, there are cliffs carved from the pre-Cambrian complex and the overlying Cambrian quarzite and limestone. Northeast of Ogden the Cambrian is overlain by Carboniferous.

To the east, 7.2 miles (11.6 kilometers) farther on, the wide canyon of the Weber River deeply dissects the Wasatch front. This part of the front is made up chiefly of pre-Cambrian rocks, but Ogden Peak, north of the canyon, is capped by Tertiary beds. To the west is Fremont Island, rising from Great Salt Lake just

A. BED OF RICH BANDED CARBONATE ORE BETWEEN CLEAN SILICEOUS WALLS

On 750-foot (229-meter) level, Silver King mine, Park City district. From U. S. Geol. Survey Prof. Paper 77, pl. 34, *A*, 1912.

B. PIEDMONT SCARP IN WASATCH RANGE

On Bonneville delta near Weber Canyon. While the Lake Bonneville waves were shaping the Provo shore line the Weber River built a large delta at the edge of the lake. From U. S. Geol. Survey Prof. Paper 153, pl. 15, *B*, 1928.

south of Promontory Point, which is the south end of the Promontory Range; and in the distant background Basin Ranges west of the lake are visible.

The settlement of Woods Cross is a center for agriculture and canning.

North and east of Layton, 1.2 miles (1.9 kilometers) beyond Woods Cross, the barren cliffs of the west front of the Wasatch indicate the position of the main Wasatch fault and afford evidence of the fault movement.

West of Layton is a beet-sugar factory which uses beets produced in the adjacent region. To the east broad green fields of hay and sugar beets extend clear to the base of the mountains; these are on the old lake bottom which is now free from alkaline salts.

The route swings east toward a great embayment in the Wasatch front, which is still made up of pre-Cambrian metamorphic rocks dissected by numerous canyons. Two miles (3.2 kilometers) beyond is a viaduct. To the west, near the lake, drilling for oil to a depth of 1,000 feet (305 meters) developed some inflammable gas but no oil (51). Three-quarters of a mile (1.2 kilometers) farther along is a view to the east and southeast of Farmington. On the Wasatch front ledges of pre-Cambrian quartzite with quartz veins are masked at the base by high-level beach terraces. Along this portion of the Wasatch, extending south for 20 miles (32 kilometers) from Weber Canyon, Gilbert (54) detected evidences, on high slopes of the range, of an ancient peneplain, now elevated and tilted westward.

Within recent years this Farmington area has been the scene of heavy floods from streams rising on the western slope of the Wasatch Range and washing detritus and large boulders down westward across the highway to bury the road, ruin the fields, and submerge houses to the second story. These excessive run-offs have been explained as due in part to stripping the vegetation from the western slope of the range by grazing.

At 2.8 miles (4.5 kilometers) from Farmington the view west across Great Salt Lake to Antelope Island shows high-lying beach levels. The town of Bountiful, 3½ miles (5.6 kilometers) farther along, is the center of the cherry-growing district. The mountain front to the east shows pre-Cambrian quartzite with quartz veins and a general northerly dip; it is contoured by a succession of lake terraces, three of which are particularly well marked, and cut by recent canyons. In the distance the Tertiary (Wasatch) dips east against pre-Cambrian and early Paleozoic beds. In the foreground evidence of the power of recent flood waters is seen in deposits of detritus 6 to 8 feet (1.8 to 2.4 meters) deep and in slopes strewn with large boulders. On the

Wasatch front just north of a point opposite the side road to Woods Cross, Carboniferous limestone and overlying Tertiary beds give way to high ledgy semiwooded slopes on the pre-Cambrian. The road cuts across an embayment in front of the range, which is here capped by Tertiary beds.

From a point about 4 miles (6.4 kilometers) north of Salt Lake City the highway passes south for about 1½ miles (2.4 kilometers) along the west base of one of the best-defined salients extending west from the main fault zone of the Wasatch, known as the City Creek salient (54). This salient is made up of Paleozoic limestone, Devonian (Threeforks), and Mississippian (Madison), dipping to the south and locally to the east; and these beds, as well as the main range to the east, are capped with Eocene (Wasatch) conglomerate. This broad spur has been explained as separated from the main range by a post-Eocene fault (54). The west slope of the salient immediately east and above the highway shows steep north-south fracture planes dipping 70° W. Limestone breccia, which marks faulting parallel to the Wasatch fault, limits the salient on the west. Cemented lake gravel attached to this fault scarp indicates recent elevation on this subsidiary fault amounting to about 40 feet (12 meters). Hot springs, as at Municipal Pool and Becks, point to the existence of deeply penetrating fissures and to the subsidiary of the Wasatch fault as their pathway from depth. Gilbert's conception of the structure and origin of this and similar salients is shown in Figure 7. Passing the Municipal Bath on the east and a brick hospital on the west, the route turns southeastward and enters Salt Lake City.

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Excursion 4.—PARK CITY MINING DISTRICT

By John M. Boutwell

ABSTRACT

In the central part of the Wasatch Range, along the axis of the east-west Uinta anticlinal uplift, intrusive granodiorite, quartz diorite, and diorite porphyry have broken upward and eastward across a succession of siliceous and calcareous sediments, from Mississippian to Jurassic in age, aggregating 10,000 feet (3,050 meters) in thickness. (See pl. 8.) On the north limb of this anticline, in the Park City district, these sediments were extensively fractured, metamorphosed, and mineralized. The prevailing fracturing and fissuring took place roughly parallel to the master Uinta axis, easterly or northeasterly, and in certain localities, in which great wedges of sediments were forced eastward, the overthrusting took place along northerly fractures. Persistent dioritic dikes extend out from the parent intrusive masses along the master northeast zones of fracturing, and the solutions that passed from the molten dike material along the guiding fissures transported the elements for the formation of metallic ores. These elements were deposited as veins in the fissures and as replacement bodies along certain calcareous beds of the Park City (Pennsylvanian and Permian) and Thaynes (Lower Triassic) formations that were traversed by these fissures. These ores have high contents of silver and lead, with less copper and zinc. They have been mined from the surface to a depth of approximately 4,000 feet (1,220 meters) and have yielded $250,000,000. Their persistence both laterally and in depth argues most favorably for the future of the district.

HISTORY

Prospecting for minerals in this area was undertaken apparently under the guidance of soldiers and emigrants who had gained mining experience in California. In 1863, the year after the arrival of Colonel Conner's California Volunteers, the first metal discovery and location in Utah was made in Bingham Canyon. Prospecting was then actively carried on in Bingham, in Rush Valley near Stockton, in the Cottonwood region, and elsewhere; and in 1864 the first discovery of silver-bearing rock in the Wasatch Range was made at the head of Little Cottonwood Canyon. Prospecting continued throughout the central Wasatch in Little Cottonwood and Cottonwood Canyons, on American Fork and Snake Creek, and in Parleys Park, and in 1869 the Walker & Webster claim, in Park City, was located. In 1870 the first shipment of ore from this region was made.

In 1872 discovery of the famous Ontario ledge stimulated development of lode ores. Prospecting lodes on Crescent Ridge,

on the west, led to the discovery of bodies of rich lead-silver ore in beds on Treasure Hill and in 1892 to the opening of extensive bodies of rich bedded ore in Silver King ground. The output from beds then rapidly increased, and that from lodes relatively decreased until comparatively recent years, when the development of relatively valuable lode ores in the Silver King, Daly West, Daly Judge, and Park Utah mines has greatly increased the relative value of the output of lode ores.

The large silver content in these ores has resulted in a succession of periods of more and less activity coincident with the rise and fall in the price of silver. On the other hand, increased facilities for mining, as in drainage, ventilation, and transportation through a series of long drain and work tunnels, have reduced costs of mining and increased the extent of minable ground. Finally, higher recovery of metal content through greatly improved methods of treatment, notably flotation, has served both to increase the quantity of ore that can be handled and to increase the yield and profits.

At the present time about 60 square miles (155 square kilometers) of ground has been opened and explored through a series of shafts reaching a maximum depth of 2,000 feet (610 meters) with levels aggregating about 250 miles (402 kilometers) in length and several long tunnels aggregating about 10 miles (16 kilometers).

GEOGRAPHY

Situation.—The Park City mining district is in the north-central part of Utah, 25 miles (40 kilometers) southeast of Salt Lake City, on the eastern slope of the Wasatch Range, 3,000 to 6,000 feet (915 to 1,830 meters) above the city, or 7,000 to 10,000 feet (2,130 to 3,050 meters) above sea level. It lies on the northerly slope of a prominent spur extending from Clayton Peak on the main divide of the central Wasatch eastward toward the Uinta Range. The district embraces an area about 10 miles (16 kilometers east and west by 6 miles (9.6 kilometers) north and south. From this dividing tract the drainage escapes, chiefly by narrow, steep canyons northward into East Canyon Creek, in part northeastward into the Weber River, and in part southward into the Provo River; thus all eventually flows westward across the Wasatch Range through narrow, deep rock-walled canyons. Park City (altitude 6,984 feet, or 2,129 meters; population in 1930, 4,281) lies at the foot of the main north slope, on the north-central side of the district. It is reached by two railroads and two transcontinental automobile routes—the Lincoln Highway (U. S. route 90) and the Victory Highway (U. S. route 40).

The principal mines are accessible by good mountain automobile roads and also by electric tram through long work and drain tunnels.

Climate and vegetation.—The climate is bracing and healthful, with short, cool summers, marked by considerable rainfall, and long, rigorous winters with heavy snowfalls and low temperatures. Springs, natural rock basins, and subsurface sources tapped by mine workings yield a constant supply of water for domestic and industrial use. In early days the well-watered slopes supported pine trees 3 to 5 feet (0.9 to 1.5 meters) in diameter, but cutting for mine use has reduced this growth to a few isolated groves of small trees. Young aspen abounds in areas underlain by calcareous or readily comminuted formations and is sparse in areas of siliceous massive formations. In the higher areas the growth consists chiefly of scrubby evergreens with a little mountain mahogany (*Cercocarpus*).

ORE RESERVES, TREATMENT, AND PRODUCTION

Reserves and future.—The ore reserves of the mining properties of this district have not been made public. Owing to the nature of the ore occurrence in bedded replacement bodies and in lodes, and the resulting irregularity and discontinuity of the ore bodies, determination of ore reserves and ore possibilities would be most difficult, but the combination of geologic factors that attended the deposition of the valuable ore bodies already discovered is known to have existed in undeveloped portions of the district. In the extreme southwestern part and on the east side of the district exploration is extending beyond the limits of known ore bodies in search of new ore. Judged by geologic evidence, the possibilities of developing good ore in virgin ground beyond the limits of the present productive ground are highly favorable and imply a considerable extension of the productive life of this district.

Mining methods.—The lode ores, where width of lode permits, are mined by square-set and fill methods. The bedded ores are mined by stull and fill except where they are thick enough to warrant square sets.

Ore treatment.—The ore is usually concentrated before smelting, although a very small part is still sent direct to the smelter. Through flotation an extremely high saving of metal content in concentration is effected. The product yields lead, silver, gold, copper, and zinc.

Mining costs.—The total cost of mining lode ores averages \$5 to \$7 a ton, and the cost of mining bedded ores averages \$7 to \$12 a ton.

Production.—The recorded production from this district from the earliest shipments to the end of 1930 is as follows: Gold, $8,049,184; silver, 199,401,578 fine ounces (6,181,448,918 grams); copper, 54,062,149 pounds (24,327,967 kilograms); lead, 1,958,-571,369 pounds (881,357,116 kilograms); zinc, 332,306,387 pounds (149,537,874 kilograms); total value, $287,627,721. Of this total $163,910,088 came from the properties now owned by two mining corporations—the Silver King Coalition Mines Co. ($73,792,893) and the Park Utah Consolidated Co. ($90,117,-195). The value of the total output from the district is approximately $300,000,000.

GENERAL GEOLOGY

The Wasatch Range reaches its greatest altitude, its most rugged relief, and its most complex geologic development in its central portion. Here series of sediments from Algonkian to Tertiary, inclusive, have been complexly folded and faulted and the western portion thrust over the eastern portion. Along the transverse east-west course of the Uinta axis a series of stocklike intrusives has broken upward and eastward across the Wasatch Range. In certain of the inclosing sedimentary formations, as along the divide between Cottonwood and Little Cottonwood Canyons and along the divide between Thaynes Canyon and Snake Creek, within the zone of their contact with these intrusives, numerous characteristic contact-metamorphic minerals have been developed. In the eastern part of the Park City district Carboniferous quartzite (Weber, Pennsylvanian) completely overrode two formations and is thrust upon Lower Triassic shale (Woodside). (See pl. 8.)

Sedimentary rocks (66).[8]—The sedimentary rocks of the Park City district range from Mississippian to Jurassic. Within the main district they fall into six distinct formations.

The Mississippian crops out to the south of the area and is believed to have been encountered by some of the deepest mine workings.

The Weber quartzite (Pennsylvanian), a fine-grained massively bedded quartzite, lies next above, with an approximate thickness within the district of 1,500 to 2,000 feet (457 to 610 meters).

The Park City formation, immediately overlying the Weber, is made up of limestone, sandstone, and shale to an aggregate

[8] Numbers in parentheses refer to bibliography, pp. 81–82.

thickness of 550 to 590 feet (168 to 180 meters). It constitutes a well-defined unit with fossils of Pennsylvanian age in the lower part and of Permian age in the upper part. The characteristic Phosphoria formation of the Idaho phosphate-mining region has been found about 30 miles (48 kilometers) to the west, with abundant characteristic fauna and a thickness of 499 feet (152 meters). In the Park City district the Phosphoria formation is represented by the upper two members of the Park City formation (73). The unconformable relation between the Park City and the underlying Weber quartzite, which was not definitely ascertained at the time of the original Park City survey (65), the difference in thickness of beds and the nature of the contact as imperfectly exposed along certain underground workings having raised a question as to the existence of an unconformity without affording definite proof, has since been determined clearly by adequate exposures in Weber Canyon, 50 miles (80 kilometers) to the north (64).

The Woodside shale, next overlying the Park City formation, is uniformly fine-grained dark-red shale. Its thickness varies several hundred feet within a few miles, but in this district appears to be about 700 feet (213 meters). It is lithologically similar to the overlying formations, of Lower Triassic age.

The Thaynes formation is made up of three main portions—the upper, largely calcareous, 630 feet (192 meters); the middle, red shale, 115 feet (35 meters); and the lower, limestone and sandstone, 450 feet (137 meters), making a total of 1,195 feet (364 meters). Fossils are abundant (66). Although some evidence of unconformity within the Thaynes was found in the original survey of the district, it was mapped as one formation on general lithologic and faunal evidence. In recent years detailed paleontologic and stratigraphic study in the near-by Fort Douglas area has yielded evidence favoring the division of this formation into two parts, the lower about 600 feet (183 meters) thick and the upper about 1,000 feet (305 meters) thick, each part containing a distinctive fauna (74). Accordingly, for stratigraphic and paleontological purposes it has now been divided into the Pinecrest and Emigration formations. The abundant and interesting fauna of these two new divisions of the original formation may be studied and collected at several points, as in Woodside Gulch, on Crescent Ridge above the King mine, and on the north side of Cottonwood Canyon along the ridge adjoining Mule Hollow on the north side.

Next above follows the Ankareh formation (Triassic?), characterized by bright-red shale and sandstone and a few thin beds of limestone, the whole aggregating in this district about 1,100

feet (335 meters) in thickness and in the Fort Douglas area about 450 feet (137 meters).

The highest formation outcropping in the district is the Nugget sandstone (Jurassic), a massive coarse grayish-white cross-bedded sandstone carrying no fauna but some petrified wood. It is at least 500 feet (152 meters) thick.

Igneous rocks (66).—The ore deposits of the Park City district are clearly associated with igneous rocks. These rocks lie in the great zone of igneous activity that extends entirely across the Wasatch Range and is marked by the monzonitic intrusive of the Bingham district, in the Oquirrh Range; the porphyritic granite at the mouth of Little Cottonwood Canyon, in the Wasatch Range; the granodiorite near Alta; the dioritic mass of the Park City divide; and beyond on the east the andesitic flow filling the valley between the Wasatch and Uinta Mountains.

Igneous rocks occupy nearly one-third of the area of this district. Three petrographic types are present—diorite, diorite porphyry, and andesite. The diorite forms the highest peak within the district, with rugged ridges, and gives way northeastward to extensive irregular masses of coarse diorite porphyry and still farther northeast to the andesitic flow.

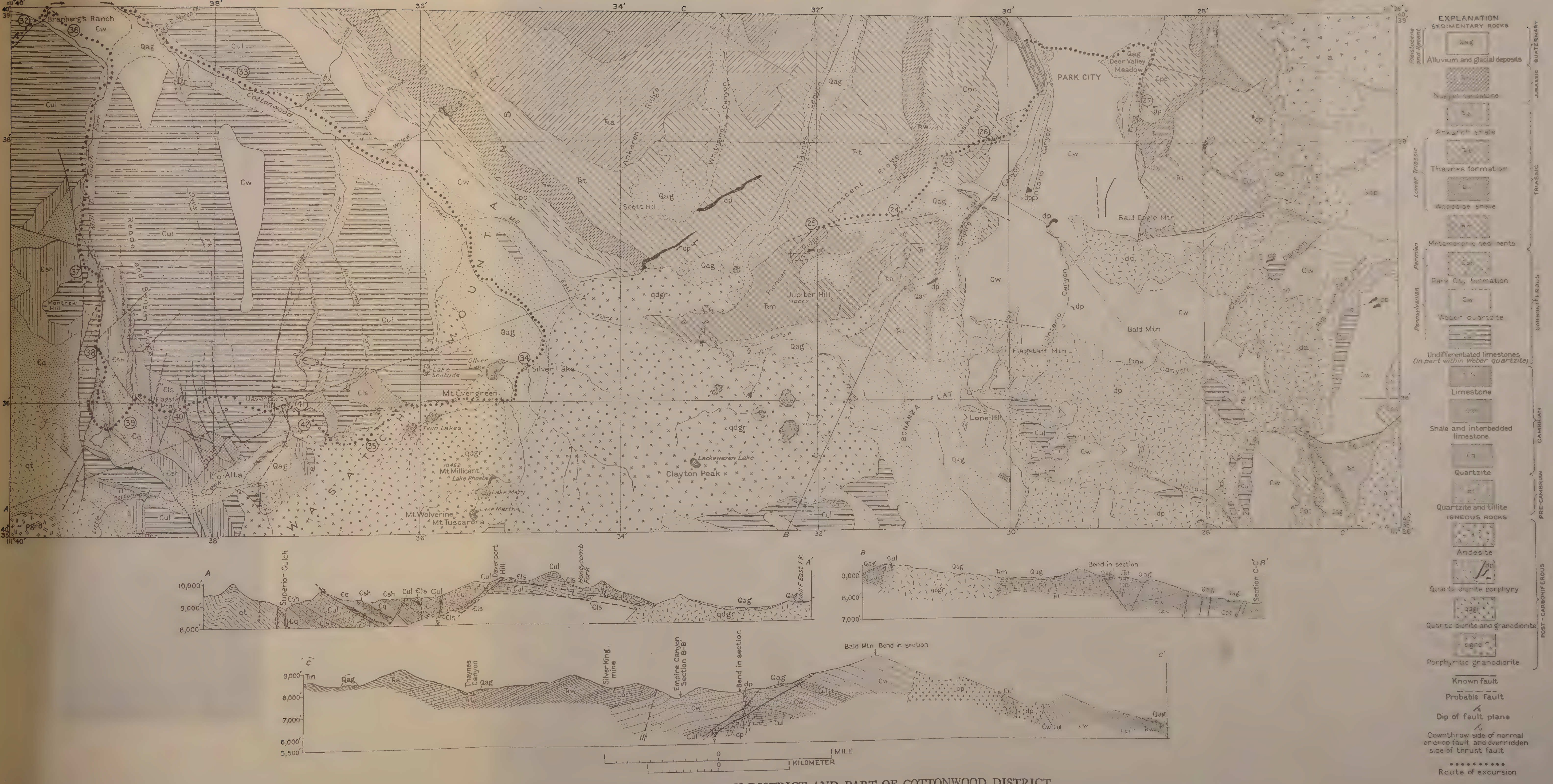
The diorite is a dark-gray fine even-grained rock. The light minerals are chiefly plagioclase (between albite and oligoclase) with some orthoclase and quartz; the dark minerals are biotite and hornblende with accessory apatite, magnetite, pyrite, and titanite.

The quartz diorite porphyry is a light-gray spotted rock. The phenocrysts consist of plagioclase feldspar, hornblende, biotite, quartz, and rarely augite; in the groundmass particles of biotite, feldspar, and pyrite may be present.

A few small dikes of peridotite (picrite) are also present.

The intrusive diorite and quartz diorite porphyry cut all the sedimentary formations, and the andesite includes areas of porphyry. It appears that the diorite is not earlier than Triassic, that the porphyry is at least as late as early Triassic, and that the andesite is later than the Wasatch (Eocene).

Structure.—The geologic structure is that of an anticline with axis trending roughly north and south and pitching northward. (See pls. 8, 9.) The eastern limb descends beneath andesitic flows, and the western limb passes into a wide flaring syncline pitching north. The Park City arch, comprising all the geologic formations, embraces the entire district. It is broad and low, the formations on its flanks dipping gently northwest, east, and southeast. This broad structure is modified by minor folds, by strong faults, and by intrusion (66).



GEOLOGIC MAP AND STRUCTURE SECTIONS OF PARK CITY DISTRICT AND PART OF COTTONWOOD DISTRICT

Park City portion from U. S. Geol. Survey Prof. Paper 77, pl. 2, 1912; Cottonwood portion from U. S. Geol. Survey Prof. Paper 111, pl. 27, 1920. Numbers in circles indicate localities referred to in the text.

PARK CITY MONOCLINE

Shows monoclinal structure of sedimentary formations. Weber quartzite in foreground, Park City formation capping first spur, Thaynes formation on the second and third cuestas, and heavy Triassic sandstone forming the prominent cuesta in right background, all dipping northwest. Park City in middle ground, Ontario mill in left foreground, Silver King mine and Crescent Ridge in left background. From U. S. Geol. Survey Prof. Paper 77, pl. 4, *A*, 1912.

Two major parallel northeast zones of fracturing traverse the district—the Ontario-Daly West zone in the eastern part and the King zone in the western part. Each zone is composed of a series of fissures trending N. 60°–70° E. and dipping commonly about 70° NW. Each of these zones has been followed for more than 2 miles (3.2 kilometers) along the strike and more than 2,000 feet (610 meters) on the dip, and each is characterized by displacement down the dip ranging from a few feet to a few hundred feet. Southwest of the King zone the strong Crescent fault, dipping steeply southeast, has dropped the Nugget sandstone on the south into juxtaposition with Thaynes limestone on the north, approximately a 1,000-foot (305-meter) displacement. Southwest of the Ontario zone a similar displacement has occurred on the "back vein." In the northeastern part of the district, on extensive overthrust faults along a north-south fracture zone known as the Frog Valley zone, the Weber quartzite has overridden eastward two formations, the Park City and Woodside, aggregating a stratigraphic thickness of approximately 1,500 feet (457 meters). At its south end in the east-central portion of this area, this thrusting force was translated into an eastward movement of a wedge between the Hawkeye fault, in McHenry Canyon, on the north, and the Cottonwood fault, in Cottonwood Canyon, on the south, for a distance of about 2 miles (3.2 kilometers). Across the entire southern portion of the Park City arch a great series of irregular stocks and dikes have broken from the Clayton Peak stock of quartz diorite on the southwest to the irregular mass of quartz diorite porphyry on the extreme east.

Geologic history.—The sequence of sediments present in this area indicates three periods of rather deep water in Mississippian, Permian, and Triassic time, separated by three periods of shallow beach and mud-flat conditions marked by the Weber quartzite and the Woodside and Ankareh shales. The uplift of the Wasatch Range at the end of Cretaceous time was the maximum land movement, but other movements indicated by unconformities took place between Pennsylvanian and Permian, between Permian and Triassic, and between Triassic and Jurassic time; and evidences of lesser oscillations are found in the Pennsylvanian between the Weber and Park City and throughout Triassic time, as in the Woodside and Ankareh.

Contact metamorphism.—Extensive intrusions of diorite and diorite porphyry traversing all sedimentary formations have induced intense metamorphism in the zone of sediments adjoining the intrusives. The metamorphism is most marked in the divide formed on resistant rocks along the northern contact of

the main chain of intrusives. The rocks are in many places so greatly altered in color, texture, and composition that their original character is entirely lost, but in some localities formations and even individual beds may be traced from the normal unaltered state toward the contact through successive stages of metamorphism. Limestone is thus seen to have been turned into marble, with characteristic development of contact-metamorphic minerals, such as garnet, epidote, vesuvianite, spinel, and chabazite, and metallic minerals, such as specularite, sphalerite, pyrite, chalcopyrite, and magnetite. Locally limestone is entirely replaced by solid sulphides. Shale under similar influences has turned from red to green and become like hornstone, mainly through the development of epidote and silica, and sandstone has become quartzite.

ECONOMIC GEOLOGY

Ores of lead, silver, zinc, and copper, partly oxidized in superficial portions, occur on persistent northeast lodes and in comparatively extensive replacement bodies along selected beds of limestone in the Park City and Thaynes formations adjacent to northeasterly feeding fissures, in places associated with quartz diorite porphyry.

Character of ores.—The ores are valued chiefly for their lead and silver content and secondarily for their copper, zinc, and gold. The chief source of lead is galena, and a relatively small amount is derived from cerusite, anglesite, pyromorphite, cerargyrite, mimetite, massicot, bindheimite, jamesonite, and bournonite. Silver is derived chiefly from galena and tetrahedrite. Copper occurs chiefly in the form of tetrahedrite and sparingly in azurite, malachite, chrysocolla, chalcanthite, chalcocite, and bournonite. Zinc is found mainly in the form of sphalerite and in slight amounts as calamine and goslarite. The gangue minerals are pyrite, quartz, calcite, barite, fluorite, and pyrolusite.

The alteration of galena-tetrahedrite ore in superficial parts of certain ore beds to a depth of 1,200 feet (366 meters) yields an interesting series of oxidation products including bindheimite and massicot.

In early days rich lead-silver-copper ores were opened, and high silver contents were frequently found. At present the bulk of the ore is of lower grade and requires concentration. Thus to-day crude first-class ore runs, per ton, lead, 64.67 per cent; silver, 69.98 ounces (2,176.62 grams); gold, 0.0551 ounce (1.71 grams); and copper, 1.3 per cent. Low-grade, milling ores are concentrated to a grade equivalent to the crude ores; thus lead concentrates run, lead, 64.57 per cent; silver, 63 to 75 ounces

(1,959 to 2,332 grams); gold, 0.1039 ounce (3.231 grams); and copper, 2.06 per cent; and zinc concentrates run, lead, 2.69 per cent; silver, 10.03 ounces (311.96 grams); gold, 0.0156 ounce (0.49 gram); copper, 0.40 per cent; and zinc, 59.13 per cent.

Occurrence of ores.—The principal ore bodies have been found in the ground traversed by the two major northeasterly fracture zones (the Ontario at the southeast and the King at the northwest), which in places are occupied by dioritic dikes. These bodies occur within the northeast fissures, between walls of quartzite and limestone as veins and lodes, and also along the bedding of certain limestones adjacent to these fissures as replacement bodies. The prevailing trend of the lodes is N. 50°–70° E., and their usual though not universal dip is toward the northwest. The bedded ore bodies occur in greatest number and extent in the Park City formation, and to a less extent in the Thaynes formation. Within the Park City formation the replacement ore consistently favors certain limestone members, most of which lie in the lower portion of the formation. (See pl. 7, *A*.) The dioritic intrusive masses present in the vicinity of ore bodies are comparatively small; the large parent stocks of diorite and diorite porphyry lie farther south. Some displacement occurred on the master fissures, in part before and in part after the deposition of the ores in the fissure zones and along the bedding. Localization of ore into shoots is recognized, although not as well defined as in some other mining districts. The shoots between quartzite walls are determined apparently by the form of the inclosing fissure, and those along limestone beds by the course of the intersection of the feeding fissure with the selected limestone member.

Genesis of ore.—Between early Triassic and early Tertiary time dioritic intrusives invaded this area, breaking upward and northeastward across the sediments, and following along master northeasterly fissures they metamorphosed the sediments and induced the deposition of rich lead-silver ore in certain members of the calcareous formations. After cooling of the magma to partial rigidity the composite country rock was broken by persistent northeast fractures. Along these pathways, as trunk channels from deep-lying still molten magma, ore-forming material, together with hot gases and alkaline aqueous solutions, passed upward and outward and was deposited as veins along northeasterly fissures, partly by filling and partly by replacement of walls, and as replacement bodies along certain purer beds of limestone. Recurring movement along the northeasterly feeding fissures crushed the lode ore in them and displaced the beds of ore adjoining them. Waters descending from the surface along these fractures encountered these primary sulphide ores and

altered them in their more superficial and accessible portions to rich sulphates, carbonates, and oxides; and this alteration and enrichment is still taking place.

SILVER KING MINE

Most of the known productive ground in this district is owned and operated by two corporations—that lying on the west and north by the Silver King Coalition Mines Co. and that lying on the south and east by the Park Utah Consolidated Mining Co. Each controls large holdings and has extensive underground workings, and each has paid many millions of dollars in dividends.

The property of the Silver King Coalition Mines Co. embraces the western portion of the known productive ground and occupies the western limb of the Park City anticline. The main mine plant is in Woodside Gulch 1 mile (1.6 kilometers) southwest of Park City. The mine may be entered through the King shaft at the main plant, through the King tunnel by the adit just below and northwest of Park City, or through the Alliance tunnel, in Empire Canyon at the mouth of Walker & Webster Gulch.

In the early days of this camp the bulk of the output came from the great Ontario lode, in the east side of the district. In 1888, however, rich ore was discovered outcropping in the Tenderfoot claim, in Woodside Gulch. This was followed downward to the south and west, and additional tracts of ground were successively acquired and explored. At the present date the original shoot has been opened and mined for a distance on the strike of over 8,000 feet (2,438 meters) and to a depth below the collar of the main shaft of about 1,400 feet (427 meters). This and other ore zones in the same system have now been developed in places to a depth below the surface of about 4,000 feet (1,219 meters). Laterally the underground workings of the property extend from Empire Canyon, on the east, well toward Scott Hill, on the west, and from the mouth of Thaynes Canyon, on the north, to Jupiter Hill, on the south, beneath an area approximately 3 miles (4.8 kilometers) square, for an aggregate distance of approximately 75 miles (121 kilometers).

The total dividends paid from ores mined from this company's ground exceed $25,000,000. In 1929 this mine was the largest producer of silver in Utah and ranked second in the production of lead, third in zinc, and sixth in copper. The value of the gross production from the mine exceeds $90,746,140.

The King ground embraces a great extent of the Park City formation, the later Thaynes formation, and the underlying Weber quartzite, all dipping gently northwest on the west limb

of the Park City anticline. These formations are truncated on the south by the great chain of dioritic intrusives, some of which penetrate and follow certain northeasterly fissures as narrow dikes. The strong, persistent fissures of the King system traverse this composite country rock in a general northeasterly direction (N. 50°–70° E.) and dip commonly northwest at steep angles. The great Crescent fissure, at the south side of the property, dips steeply southeast. Faulting has taken place on these fissures, at two or three distant periods, usually of small amount, though on the Crescent fissure the displacement is about 1,000 feet (305 meters).

Ore.—The ore is exceptionally high in lead and silver, and lower in gold, copper, and zinc. On the upper levels it was a high-grade mixture of oxides and sulphides; at intermediate depth it was a high-grade sulphide; and at present depths it is a concentrating grade of sulphides yielding lead, silver, zinc, copper, and gold. Galena forms the chief source of the lead and together with tetrahedrite furnishes most of the silver. Copper is derived chiefly from tetrahedrite, and zinc from sphalerite. The characteristic gangue consists of quartz and pyrite and rarely fluorite. The rich King ore is made up of massive coarse galena intergrown with tetrahedrite. On oxidation this yielded bindheimite, massicot, cerusite, anglesite, azurite, malachite, and chrysocolla. Fluorite is present locally.

Occurrence.—The ore bodies in King ground occur as veins or lodes or as replacement beds. Between walls of Weber quartzite, which underlies this property throughout, northeasterly fissures connected with the great dioritic intrusives at the southwest inclose well-defined persistent veins. In their extensions upward through the overlying limestone formations, especially the Park City, these veins show notable increase in width. Along particular beds in the Park City the ore extends out from the veins into lenticular replacement bodies. In the veins localization of these ores into shoots is indefinite and irregular; but in replacement bodies it is common and was clearly determined by the intersection of the feeding fissures with the selected bed. Broadly, these shoots appear to pitch to the southwest.

Origin.—The evidence indicates that these rich lead-silver ores were derived from the great dioritic magma at the southwest, that some were deposited contemporaneously with intrusion in adjoining calcareous sediments as contact-metamorphic deposits but that subsequently and in major part the ore-bearing agents moved from the magma upward and northeastward along trunk channels afforded by master northeasterly fissures, and ore was deposited as veins within the fissures and as replacement bodies along adjoining selected limestone beds.

ITINERARY

The route for the Park City coincides with that for the Wasatch-Uinta excursion for the first 30 miles (48 kilometers), from Salt Lake City to a point on the north outskirts of Park City. (See pp. 58–60.)

At Park City Junction, about 1½ miles (2.4 kilometers) north of Park City, the route to the Silver King mine turns south and passes southeastward around the north side of the Park City anticline. On the southwest can be seen the west limb of the anticline, comprising the Park City, Woodside, Thaynes, Ankareh, and Nugget formations (Pennsylvanian to Jurassic), dipping northwest. To the east the Park City formation strikes east over the Weber quartzite, forming the crest of Mount Masonic.

23.[9] If the King mine is entered by descending the King shaft the route thence will lead up Woodside Gulch around Weber quartzite ledges to the overlying Park City formation as far as the mine, where the overlying Woodside shale is well exposed in the rear of the mine office. If the party enters the mine by electric train through the King tunnel, the route leaves the main road about 2 miles (3.2 kilometers) northwest of Park City and strikes up to the adit at the mouth of Thaynes Canyon, where can be seen in the foreground the Woodside, Thaynes, Ankareh, and Nugget formations and in the distance, at the head of Thaynes Canyon, Jupiter Hill (altitude 10,007 feet, or 3,050 meters), made up of argillite metamorphosed from Ankareh shale.

The visit to this property will afford opportunity to observe the stratigraphic succession from Pennsylvanian (Weber) to Triassic (?) (Ankareh), inclusive, the King system of northeasterly fissures, intrusive dikes of quartz diorite porphyry and peridotite, faults 50 to 1,000 feet (15 to 305 meters) in displacement, characteristic sulphide ores, and typical occurrences of veins and replacement bodies.

On the surface at the King shaft the concentration mill may be seen in operation, in the treatment of these mixed sulphide ores by flotation.

From the mine office not only the formations and structure in the immediate vicinity are well exhibited, including the Woodside and Thaynes formations dipping northwest, but also the eastern portion of the district and, beyond, the extensive valley filling of andesitic flows and agglomerates, and still farther away the outlines, formations, and structure of the Uinta Range.

24. By a walk from the collar of the King shaft up Walker & Webster Gulch for a distance of about 1 mile (1.6 kilometers)

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[9] Numbers refer to corresponding numbers on Plate 8.

fossils characteristic of the Thaynes formation (lower Triassic) can be seen and collected.

25. Along the divide to the south-southwest, at a distance of about half a mile (0.8 kilometer), the outcrop of the Crescent fault is well shown, bringing Thaynes limestone on the north side against Nugget sandstone on the south, thus indicating a displacement of more than 1,000 feet (305 meters). To the southwest, a mile (1.6 kilometers) beyond, around the head of Thaynes Canyon, limestone with characteristic contact-metamorphic minerals, including epidote and specularite, is abundant.

26. Less than 1 mile (1.6 kilometers) from the shaft down the gulch exposures affording a characteristic fauna of the Park City formation may be seen.

27. About a mile east of Park City by way of Deer Valley a grassy meadow gives way to an abrupt north-south wall. This ridge is made up of the upper part of the Park City formation, dipping east beneath Woodside shale. The flat along the base of the ridge to the west is on Weber quartzite, which normally lies much lower. To the south, at the head of a broad valley, a strong north-south fault brings Weber on the west against Park City and Woodside on the east. This indicates an overthrust from the west to the east along the Frog Valley fault zone, dipping west, and thereby the burial by overriding of the Park City formation. Beyond to the south both Park City and Woodside and part of the Thaynes formation are overridden. This is an example of the great system of overthrust faults extending from the Canadian Rockies at the north to the Grand Canyon at the south, as represented by overthrusts of the Glacier National Park, in Montana; the Bannock thrust, near Montpelier, Idaho; and others near Coalville, Oakley, and Cedar City, Utah.

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Excursion 5.—COTTONWOOD REGION

By John M. Boutwell [10]

The principal features of geologic interest in the Cottonwood region include the classic pre-Cambrian and Cambrian section of Walcott, the type Carboniferous, Permian, and Triassic section of the Wasatch Range, the Cottonwood granite of Zirkel, the Alta granodiorite and Clayton Peak diorite, with extensive contact metamorphism of adjacent sediments, several normal and overthrust faults, exposures of ancient tillite, and striking records of vigorous Quaternary glaciation.

GEOGRAPHY

The Cottonwood region lies 20 miles (32 kilometers) southeast of Salt Lake City, in the midst of the lofty, rugged central portion of the Wasatch Range. It is drained by Cottonwood Creek and Little Cottonwood Creek toward the west, and by Snake Creek and upper American Fork toward the east and south. The deep, narrow, steep-walled canyons of these streams rise by steep grades to precipitous, rock-walled amphitheaters encircling their heads. Cottonwood Creek, which empties into the Jordan River at an altitude of about 4,250 feet (1,295 meters), has its headwaters in the amphitheater about Silver Lake at about 9,300 to 9,900 feet (2,835 to 3,018 meters). The pass across the main divide to Little Cottonwood Canyon stands at 9,993 feet (3,046 meters), and Twin Peaks, farther west on the same divide, reach 11,319 feet (3,450 meters), giving a maximum relief of more than 7,000 feet (2,150 meters). A good automobile road extends up Cottonwood Canyon to Silver Lake; a mountain road leads up Little Cottonwood Canyon to Alta, the mining camp at its head, at 8,585 feet (2,616 meters); and mountain trails connect the other portions of these canyons.

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[10] Based on sections in U. S. Geol. Survey Prof. Paper 111—on geology by F. C. Calkins and on ore deposits by B. S. Butler—and on personal studies by the writer. Itinerary based on field studies from 1901 to 1931 by the writer, on field and personal memoranda by F. C. Calkins, and on field work by and a field trip with F. F. Hintze, particularly regarding the Cambrian and pre-Cambrian.

HISTORY AND FUTURE

Ore was discovered in Little Cottonwood Canyon in 1864. Prospecting in Cottonwood and Little Cottonwood Canyons followed, and from 1871 to 1877 the greatest mining activity was reached. The Emma and Flagstaff silver mines and several others of less note are located at Alta, in Little Cottonwood Canyon; and the Maxfield, Prince of Wales, Cardiff, and other mines were opened in the seventies in Cottonwood Canyon. Mining activity reached its height in the seventies and has since been revived at various periods. The high-grade ores were transported to Salt Lake Valley for smelting.

The output from 1867 to 1917 aggregated 429,495 short tons, which yielded $500,520 worth of gold, $13,215,139 worth of silver, $1,741,962 worth of copper, $10,225,640 worth of lead, and $39,283 worth of zinc, with a total value of $25,722,553.

Although mining has been carried on intermittently since the principal known rich ores were worked out in the seventies and eighties, the shortness of the open season and the high cost of transportation and of operating in this rather inaccessible camp have served to retard the normal development of mining. Most of the ore bodies, although high in grade, have been rather small. The complexity of the geology, particularly the large amount of strong and complicated faulting, has also seriously interfered with successful and profitable mining. Valuable new ore bodies will undoubtedly be discovered in this district, however, and further shipments of good ore will be made.

GEOLOGY

The Cottonwood area includes the intersection of the two dominant structural trends of this entire region, the Wasatch axis and the Uinta axis (81, 84). The general anticlinal structure that characterizes the Wasatch as a whole is interrupted in this central portion by a transverse anticline. The intersection of the forces that produced these contrary structural trends has naturally resulted in complex and significant geologic consequences.

The continuity of the north-south Wasatch folds of Paleozoic and Mesozoic sediments is here interrupted by an east-west chain of intrusive stocks (84) occupying a transverse anticline in line with the axis of the Uinta Mountains. The sedimentary rocks involved range from pre-Cambrian to Jurassic and aggregate 20,000 feet (6,100 meters) in thickness. The pre-Cambrian, forming about one-half of this thickness, is made up chiefly of quartzites and metamorphic siliceous rocks. The Paleozoic, succeeding with a slight angular unconformity, comprises 6,000 feet (1,830 meters), chiefly of limestone but including considerable shale and

some quartzite. The succession shows several interruptions, the most extensive of which is at the base of the Devonian (?) or Carboniferous limestone. The Mesozoic, represented by 4,000 feet (1,220 meters) of shale, limestone, and sandstone, in part marine, in part of continental origin, reveals only minor interruptions in deposition. Major deformation occurred at the end of Jurassic time.

The igneous rocks of this region range from quartz monzonite and granodiorite to quartz diorite porphyry and andesitic lavas and breccias. The larger intrusive bodies have intensely metamorphosed the sedimentary formations, developing a great variety of contact-metamorphic minerals, including some metallic sulphides.

Faulting, induced by the forces producing both sets of folds, as well as by intrusion of the igneous masses, was complex and profound. Great overthrusts, originally dipping west but now tilted eastward, were developed in this region; and to the east, in the Park City area, one westward-dipping overthrust zone was found. Many normal and some steep reversed faults are found. The great fault that forms the western limit of the Wasatch Range is commonly regarded as normal, with downthrow on the west of unknown amount but probably at least 10,000 feet (3,050 meters).

Evidences of active glaciation are abundant in the form of numerous typical glacial deposits and well-defined traces of glacial erosion.

Ore deposits carrying silver, lead, zinc, gold, and copper are associated with fissures parallel to the trend of the northeast chain of intrusives and with thrust faults. They were formed chiefly by the replacement of Paleozoic limestone.

SEDIMENTARY ROCKS

The sedimentary formations of the Cottonwood region fall in the pre-Cambrian, Cambrian, Devonian, Carboniferous, and Triassic. (See pl. 8.)

Pre-Cambrian.—One of the classic sections of late pre-Cambrian (Algonkian) rocks is exposed along Cottonwood Canyon (84) with a thickness of 11,000 feet (3,350 meters). Walcott regarded as pre-Cambrian all or most of the strata below the fossiliferous Cambrian shale. According to later studies it is now held that an unconformity 1,000 feet (305 meters) below the shale marks the top of this formation, and thus that the 10,000 feet (3,050 meters) of strata below the unconformity is pre-Cambrian (84). This formation consists of alternating beds of quartzite, shale, and conglomerate, which are variable from place to place,

showing cross-bedding, ripple marks, and mud cracks. The materials, made up chiefly of yellow-gray sandstone and considerable purple, maroon, and green shale, are poorly sorted.

The upper portion of this formation contains a succession of thick tough dark rusty beds, usually without lamination, which are regarded as tillite (87). This material characteristically consists of angular to well-rounded pebbles of quartzite, limestone, and occasionally granite, usually less than 6 inches (15 centimeters) in diameter, embedded in a dark blue-green matrix made up of rounded or angular grains of quartz and feldspar in cloudy mud, with the average texture of medium-grained sandstone (84). Varved argillite is associated with this tillite. This formation is particularly well exposed at the head of Superior Gulch.

An unconformity about 1,000 to 1,500 feet (305 to 457 meters), below the top of this quartzite series separates underlying beveled quartzites and shale from an overlying conglomerate. Some regard this unconformity as marking the division between the pre-Cambrian quartzite and the basal conglomerate beds of the Cambrian (79); others consider that this coarse fragmental bed is one of the series of tillite beds in the upper part of the pre-Cambrian, and thus that the base of the Cambrian is somewhat higher (87).

Cambrian.—The Cambrian in the middle part of the Cottonwood district (84) is made up of (*a*) a basal conglomerate 4 to 10 feet (1.2 to 3 meters) thick; (*b*) coarse gray quartzite about 800 feet (244 meters) thick; (*c*) a three-parted shaly portion comprising a gray to rusty shale member 240 feet (73 meters) thick at the base, a characteristically laminated limestone 80 feet (24 meters) thick, and a greenish-brown shale 100 feet (30 meters) thick; (*d*) limestone, in some places 600 feet (183 meters) thick, in others entirely absent owing to erosion, which has locally even removed considerable shale.

Walcott reported Lower Cambrian remains (*Olenellus*) from the base of the lowest shale and Middle Cambrian fossils from a bed 100 feet (30 meters) higher; but recent collections from this lower member have been identified as Middle Cambrian, and the upper shale and base of the limestone have yielded two brachiopods and a trilobite identified as Upper Cambrian.

Post-Cambrian unconformity.—A well-defined unconformity is traceable throughout this region obliquely truncating the highest Cambrian beds and marking the base of the next succeeding formation.

Devonian (?).—Resting unconformably upon recognized Cambrian beds at certain localities is a limestone conglomerate followed by a series of cherty and shaly dark limestones 500 to 1,000 feet (152 to 305 meters) in thickness (82, 84). An abundant

fauna has been collected from this formation (comprising about 20 distinct forms including some mammoth corals), which is considered by some paleontologists to be Devonian and by others to be Carboniferous.

Carboniferous.—The Carboniferous is represented in this area by three major divisions. The lower, about 1,500 feet (457 meters) thick, is mainly limestone but contains sandstone and shale in the upper part. Abundant lower Mississippian fossils are found in the lower part, and upper Mississippian fossils in the dark cherty portions near the top. The middle division (Weber quartzite), 1,500 to 2,000 feet (457 to 610 meters) thick, consists of quartzite and cherty limestone which yield fossils of Pennsylvanian age (82, 90). The upper division (Park City formation) about 600 feet (183 meters) thick (81), consists of gray and blue limestone, in places cherty, with some sandstone, and, in its upper portion, a dark carbonaceous shale. It contains characteristic Pennsylvanian and Permian faunas. At several localities this formation has been observed to rest upon the underlying quartzite (Weber) unconformably (79), but this relation is not well displayed in the Cottonwood region.

In the first detailed stratigraphic and paleontologic study of the Park City formation in this region, in which a section was measured on the north side of Cottonwood Canyon, the entire thickness of about 590 feet (180 meters) was regarded as a single formation containing fossils of Pennsylvanian and Permian age. The Permian fauna of the Phosphoria formation was not found. Although this well-known Permian formation has not yet been proved to be represented in the Cottonwood area, it is known in the adjacent Fort Douglas area, and further detailed field study in the intervening region may be expected to reveal valuable information on this subject.

Triassic.—Overlying the Park City formation in this area is a thick series of red shales, sandstones, calcareous sandstones, and some limestones. This series falls into three major divisions, according to lithologic character—at the base, a red shale (Woodside) 1,100 feet (335 meters) thick; next above, a two-parted sandy calcareous formation (Thaynes limestone) 1,190 feet (363 meters) thick; and, at the top, a red shale (Ankareh) 1,100 feet (335 meters) thick. The first two of these lithologic divisions, according to faunal evidence, are Lower Triassic (81); the third may be Triassic. The lower beds of the Thaynes limestone carry a Lower Triassic fauna and the upper part a younger Triassic fauna (92).

Jurassic.—The coarse gray cross-bedded sandstone (Nugget) with a basal conglomerate member overlying the Ankareh, together with associated red shale members, is regarded as probably

Lower Jurassic and lower Middle Jurassic (81). Succeeding this arenaceous formation is a well-defined fine soft dense gray limestone (Twin Creek) including a variety of calcareous members, aggregating 2,000 feet (610 meters) in thickness and yielding a Jurassic fauna. These beds and those overlying them extend north beyond the Cottonwood region.

IGNEOUS ROCKS

The great east-west zone of intrusion of the central Wasatch Range extends through the Cottonwood region. An extensive chain of irregular intrusive masses cuts upward across sediments ranging in age from pre-Cambrian to Triassic. Broadly viewed, these several masses show a similar chemical composition and appear to belong to a single dioritic magmatic province. The intrusion of this series probably took place within a relatively short time. The principal masses are, in order of position from west to east, the Little Cottonwood stock of porphyritic granite, the Alta stock of granodiorite, the Clayton Peak stock of quartz diorite, and a group of dikes of diorite porphyry. In addition there are a few dikes of white soda granite porphyry, granodiorite porphyry, black lamprophyre, aplite and pegmatite.

The porphyritic granite, or, more strictly, quartz monzonite of the Little Cottonwood stock is a light-gray medium-grained rock made up predominantly of quartz, white plagioclase (calcic oligoclase), and pinkish orthoclase, which forms the phenocrysts: it also contains small amounts of biotite and hornblende and some titanite (84). The Alta granodiorite, typical of its kind, is a light-gray medium-grained nonporphyritic rock. Its chief constituent is andesine; it contains subordinate orthoclase, quartz, hornblende, and biotite; and its chief accessories are magnetite, apatite, and titanite. The slightly older quartz diorite of the Clayton Peak stock is essentially a fine-grained dark-gray rock composed of plagioclase (andesine), biotite, hornblende, and quartz with accessory apatite, titanite, hypersthene, magnetite, and pyrite (81).

The determination of the intrusive character of these rocks involved an international geologic discussion. The geologists of the Fortieth Parallel Survey in 1869 held that these igneous masses were Archean and the foundation of the sediments. This was questioned in 1880 by Geikie (86), who considered them intrusive. In the discussion following, this view gradually gained credence (94). In 1900 the writer studied the igneous contact along the north wall of upper Little Cottonwood Canyon and ascertained concrete facts establishing conclusively the intrusive character of these igneous masses, and

in 1901 he reviewed his findings on the ground with a member of the original Fortieth Parallel Survey and led him to abandon the view of the earlier geologic pioneers (85). In brief, this evidence comprised the broken, irregular, transecting igneous contact, dikes cutting along and across adjoining sedimentary beds, the porphyritic character of the intrusives, the metamorphism of adjoining sediments, and the development of a series of characteristic contact-metamorphic minerals.

The Little Cottonwood quartz monzonite and the Alta granodiorite cut sedimentary rocks that range in composition from quartzite through shale to limestone, and they have produced strong metamorphism in all these rocks. Among the more noteworthy metamorphic effects are the widespread bleaching of dark limestone, the almost as extensive replacement of chert by tremolite, and the less common formation of forsterite and of brucite, which rarely contains residual periclase. All these magnesian minerals are formed so abundantly in magnesium-poor limestones as to indicate a transference of magnesium from the intrusive magmas.

A still more remarkable alteration has affected many dikes of diorite and granodiorite porphyry and some marginal parts of the stocks at or near their contacts with limestone. The most essential feature of this alteration is an enrichment in lime, which presumably was transferred from the limestones by magnetic solutions. The commonest product of such alteration is a pale-green aggregate of anorthite or bytownite and diopside accompanied by relatively abundant titanite. Where the process has gone further, garnet is present and may be accompanied by vesuvianite or by scapolite. At a few points ludwigite and magnesioludwigite (magnesium-iron borates) and contemporaneously intergrown sulphides of copper and zinc were developed (84).

STRUCTURE

The dominant structural feature in the stratified rocks of the Cottonwood region is a broad anticline, having an east-west axis, in line with the Uinta arch, and a strong eastward pitch. This main anticline, however, has been greatly modified by intrusion and by faulting.

The major intrusive bodies are alined along the axis of the arch, thus indicating a genetic relation to the Uinta uplift. In detail, however, their contacts have little tendency to follow bedding planes. Nearly all the dikes strike northeast.

The greatest of the many faults in the region are overthrusts, which now in most places dip eastward. These are older than the intrusions. In different sections from two to half a dozen thrusts have been found, but the lowest, the Alta overthrust, almost cer-

tainly effected the largest displacement; its throw must have amounted to several miles. On the cliffy slope east of Superior Gulch and north of Little Cottonwood Creek this fault has pushed Cambrian quartzite over Mississippian limestone. The thrust plane here, so far as can be seen in a general view, lies about parallel to the bedding of the strata both above and below.

These overthrusts originally dipped westward, and, as in most of the other overthrusts of the Rocky Mountains, each thrust block moved eastward relatively to the one beneath. Such movement is indicated by the drag folds which are found in many places, despite the fact that the thrusts commonly follow bedding planes. In a few places the thrust planes dip gently westward, and near the base of the slope south of Alta some of them have a steep reversed dip to the west.

The faults other than overthrusts, though mostly steep, are not all normal. They strike in various directions, the greatest of them nearly north-south. Most of them appear to be later than the overthrusts. Some of the faults are later than the intrusions.

Three north-south faults later than the overthrusts are outstanding in amount of throw. The greatest fault in the region, apart from the overthrusts, is the Silver Fork fault, which is apparently normal. This fracture has been traced across the Cottonwood and American Fork districts; it has a generally north-south course, with some abrupt deviations, not all of which are demonstrably due to later faulting. It has a low dip to the west, is accompanied, where exposed in mine workings, by a heavy gouge, and has a maximum throw that is measurable in thousands of feet. The Silver Fork fault, in its lateness, crooked but generally north-south course, and westward dip, resembles the Wasatch fault, at the west base of the range, but it has no direct expression in the topography.

GEOLOGIC HISTORY

The relative age of the Wasatch and Uinta Ranges may be studied advantageously at the intersection of their major structural trends in the Cottonwood region. It appears to some that the north-south Wasatch folding, accompanied by overthrusting, preceded the east-west Uinta folding, accompanied or influenced by intrusion (84). Other workers in this field believe that the dominant structure in this portion of the Wasatch is that of the east-west folds and the chain of intrusives, which is truncated on the west by the later Wasatch fault zone. Secondary later folds and faults associated with each of these major structural features serve to complicate the problem.

ORE DEPOSITS

The Cottonwood region, including Cottonwood, Little Cottonwood, and American Fork Canyons, a region of a varied sedimentary series, extensive intrusion, and profound faulting and fissuring, contains rich ore deposits.

Character of ores.—Ores mined in this region have yielded silver, lead, and minor amounts of copper, gold, and zinc.

Silver has been found to occur in galena, jamesonite, tetrahedrite, argentite, pyrargyrite, stephanite, and other minerals. Lead occurs in galena, anglesite, cerusite, plumbojarosite, wulfenite, boulangerite, and mimetite. The copper minerals present include bornite, chalcopyrite, enargite, chalcocite, azurite, and malachite. Zinc has been found in sphalerite, smithsonite, and calamine. Among gangue minerals are quartz, calcite, oxides of manganese, limonite, pyrite, and barite.

Some of the high-grade ore from the Emma mine, in Little Cottonwood Canyon, carried 100 to 200 ounces (5,110 to 6,220 grams) of silver to the ton and 30 to 60 per cent of lead and averaged 160 ounces (4,976 grams) of silver and 45 per cent of lead. Ore from the Live Yankee property, in American Fork Canyon, is known to have assayed 4 to 14 ounces (124 to 435 grams) of gold to the ton, with a high copper content.

Occurrence of ore.—All the ores of commercial importance have been found in sedimentary rocks. These occur in the form either of veins or of replacement deposits along beds, chiefly limestone beds, and in places along fracture zones parallel to the bedding, formed by thrust faults.

In limestone adjacent to intrusives mineral deposits have been opened which contain bornite, chalcopyrite, chalcocite, and magnetite, associated with characteristic metamorphic gangue minerals.

Veins occur in fissures, mainly of northeasterly trend, as fillings, with some replacement of walls, thus approaching replacement bedded deposits. Other fissure deposits are accompanied by contact minerals in replaced wall rocks and thus approach the contact type. The wall rocks of the fissures range in age from pre-Cambrian to Triassic and in character from quartzite and sandstone to limestone but are commonly limestone.

The ores of this region appear in general to have been derived from a dioritic magma, from which they escaped along northeasterly fissures, and have been deposited within these pathways as veins or along tributary limestone beds or breccia zones (thrust planes) as replacement deposits, and in less degree in limestone adjacent to intrusive rocks as contact deposits.

ITINERARY

The party will proceed southeastward through Salt Lake City, Sugarhouse, and Holladay to the mouth of Cottonwood Canyon, 14 miles (22 kilometers), thence will ascend Cottonwood Canyon eastward to the mouth of Mill D South Fork. There the more vigorous climbers may ascend this fork to its head and tramp along the main divide 2½ miles (4 kilometers) to the Alta-Silver Lake pass (altitude 9,993 feet, or 3,046 meters), then descend 1½ miles (2.4 kilometers) to Silver Lake. Others may continue up Cottonwood Canyon 6½ miles (10.4 kilometers) farther to Silver Lake, and then by good mountain trail go either on foot or horseback 1½ miles (2.4 kilometers) to the Alta-Silver Lake pass. Special stratigraphic parties may visit, instead, the type stratigraphic section on the north side of Cottonwood Canyon, and a special petrographic party may visit and study the intrusive stocks.

10.8 (17.4).[11] As the road approaches Cottonwood Canyon it affords a view eastward toward the basal slopes of the Wasatch Range to Tolcate Canyon. Light-brown Cambrian quartzite, dipping north, unconformably overlies a darker pre-Cambrian (Algonkian) quartzitic and argillaceous series, forming the spur south from Tolcate to Cottonwood Canyon.

14 (22.5). Head of Cottonwood delta. A north-south fosse cuts the delta, marking the line of movement along the Wasatch fault zone. A Lake Bonneville terrace (78) north of the canyon contours around ledges of Algonkian rock. On the south side of Cottonwood Canyon these pre-Cambrian sediments are cut by whitish Cottonwood porphyritic granite (97).

14.7 (23.7). On south wall of canyon, contact between Cottonwood granite on east and pre-Cambrian on west.

15.3 (24.6). Banded gray-brown maroon argillite, striking N. 45° E. and dipping 85° SE., and gray quartzite (Algonkian), with showing of malachite.

15.7 (25.3). On the south, spur made up of brown lower Algonkian quartzite.

16.7 (26.9). Foot of "Stairs," where the road starts up a steep grade due to massive Algonkian quartzite.

17.2 (27.7). Pond of upper power house of Utah Power & Light Co.'s hydraulic plant; exposure of series of argillites and quartzite overlain by thick series of quartzite and argillite

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[11] Distances from Salt Lake City in miles, with kilometers in parentheses.

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which appears up the canyon to the east. This is the classic pre-Cambrian section described by Walcott (95) who assigned its thickness as 11,000 feet (3,350 meters), made up of a lower quartzite, a middle slate series, and an upper quartzite. Intense folds, which can be seen below to the west, tend to increase the apparent thickness, but inasmuch as the base of the pre-Cambrian is not present the actual thickness can not be measured here; it is probably about 10,000 feet (3,050 meters).

18 (29). North of Cottonwood Canyon and west of Mill B North Fork, through faulting light-gray quartzite underlies rusty-brown Algonkian quartzite, probably about the middle of the pre-Cambrian series. Strong fresh moraines rise 150 feet (46 meters) above Cottonwood Creek (78). The canyon here follows the strike of the Algonkian quartzite.

20.2 (32.5). North of the road an outcrop shows light-gray quartzite underlying a coarse fragmental member made up of pebbles and boulders as much as 2 feet (0.6 meter) in diameter, of quartzite, argillite, schist, and granite in a dark matrix. This member is regarded by some (79) as a conglomerate marking the base of the Cambrian, and by others (87) as one of a series of beds of tillite occurring in the upper portion of the pre-Cambrian series. Recent field work has failed to settle definitely the age of this tillite, so that it appears that the "only definite conclusion warranted is that the glacial formation (tillite) is either early Cambrian or late Algonkian" (80). Thence eastward the road crosses overlying beds including maroon banded quartzite and light-gray quartzite for 0.8 mile (1.3 kilometers) to the Maxfield mine.

Near the top of the basal quartzite Walcott found *Olenellus gilberti*, proving its age to be Lower Cambrian. The overlying dark rusty shales, 140 to 210 feet (43 to 64 meters) in thickness, have yielded *Hyolithes billingsi*, *Kutorgina pannula*, *Bathyuriscus productus*, *Zacanthoides typicalis*, *Lingulella ella*, *Leperditia argenta*, and *Ptychoparia quadrans*, a fauna determining its age as Middle Cambrian. The contact between the Lower and Middle Cambrian is here unconformable.

21 (33.8). Maxfield mine. At the Maxfield tunnel the Ophir shale, forming the base of the Middle Cambrian, gives way to a characteristic pitted crinkly limestone about 80 feet (24 meters) thick, and this is succeeded by fine-grained compact brown to green shale about 100 feet (30 meters) thick. Fine-grained monzonitic intrusives, exposed beside the road east

of the Maxfield tunnel have altered the limestone locally to marble and the shale to argillite. The limestone and shale, regarded as Middle Cambrian, are separated by an unconformity from about 2,000 feet (610 meters) of overlying limestone, embracing Mississippian (84) and possibly some Devonian (89).

23 (37). [32] [12] Mouth of Mill D South Fork. Just below this fork a terminal moraine of the Cottonwood glacier crosses the main canyon and unites with a lateral moraine of the Mill D South Fork glacier.

At this point the party will divide. The main party will continue up Cottonwood Canyon by bus to a point near its head. There those who desire will walk 1¼ miles (2 kilometers) up to the pass between the headward portions of Cottonwood and Little Cottonwood Canyons. Those who prefer a more strenuous walk will proceed south 3½ miles (5.6 kilometers) up Mill D South Fork to its head and thence 2½ miles eastward along the main divide above Alta to the pass, where they will rejoin the other walking party and descend 1¼ miles (2 kilometers) into the head of Cottonwood Canyon to Silver Lake and the busses. The itinerary covering this side trip is given on pages 95–97. The main excursion continues southeastward up Cottonwood Canyon along the trace of a probable strike fault.

26.5 (42.6). On the north side of the canyon between Mule Hollow and Willow Creek is Section Ridge, along which in 1902 the first detailed section, now accepted as the standard section of the middle Wasatch, was studied and measured (81). This section, comprising about 5,000 feet (1,500 meters) of beds, includes in the Carboniferous the Mississippian, Weber quartzite (Pennsylvanian), and Park City formation (Pennsylvanian and Permian); in the Triassic the Woodside shale, Thaynes limestone, and Ankareh shale; and in the Jurassic the Nugget sandstone and Twin Peak limestone.

In this section the Permian Phosphoria of Idaho appears to be represented by a gray limestone on top of the Park City formation, with a thickness of only a few feet, but in Mill Creek, just northwest, it is 100 feet (30 meters) thick, and in the Fort Douglas area, 20 miles (32 kilometers) northwest, the characteristic Phosphoria formation is 600 feet (183 meters) thick. The Thaynes formation of this Cottonwood section, which on first study yielded an interesting

[12] Numbers in brackets refer to Plate 8.

fauna new to the West, under recent study in Emigration Canyon, 20 miles (32 kilometers) north, has yielded two distinct faunas—the Pinecrest below and the Emigration above.

The Park City formation is the one in which the bonanza bodies of silver-lead ore of the Park City district have been found; and the Twin Creek limestone is the basis for an extensive cement-manufacturing industry in Parley and Weber Canyons.

26.8 (43.1). [33] From this point, looking east, can be seen Scott Hill (altitude 10,116 feet, or 3,083 meters), made up of metamorphosed Thaynes limstone, with the dump of the Scottish Chief mine on the south slope. To the north, along the wall of the canyon, striking banding in vegetation is due to difference in bedrock. At the head of the southeast branch of the canyon the principal eminence is Clayton Peak (altitude 10,728 feet, or 3,270 meters), composed entirely of quartz diorite; and spurs to the south are made up of metamorphosed undifferentiated limestone, probably largely Mississippian. Several glacial moraines are visible.

28.7 (87.5). [34] Silver Lake (altitude 8,730 feet, or 2,660 meters), a great glacial catchment basin fed from inclosing glacial cirques. N. 25° E. is Scott Hill, of altered Thaynes; due east is a ridge of diorite; S. 40° W. is Mount Wolverine (altitude 10,700 feet, or 3,261 meters), of granodiorite; S. 70° W. is the trail through the pass to Little Cottonwood Canyon; and at the head of Cottonwood Canyon, Mount Millicent (altitude 10,452 feet, or 3,186 meters), of granodiorite.

The trail to the southwest zigzags back and forth for 1½ miles (2.4 kilometers) along the irregular contact between limestone on the north and granodiorite on the south to the Twin Lakes, in an ice-scored rock basin in granodiorite, thence southwest across granodiorite to the pass into the head of Little Cottonwood Canyon. In the contact zone are metamorphic limestone, marble, and contact minerals; to the south are fine cirques cut in granodiorite on the slopes of Mount Millicent [35]. From the pass west along the contact zone toward the City Rock mine the route crosses an overthrust fault and numerous contact-metamorphic minerals in limestone adjoining granodiorite. There is a fine view westward over Alta down Little Cottonwood Canyon.

ITINERARY OF SIDE TRIP ON FOOT

By F. C. Calkins

Those who desire to take a mountain tramp of some 8 miles (12.8 kilometers) involving a climb of about 3,000 feet (914 meters), to an altitude of about 10,300 feet (3,140 meters), in order to study faults and igneous phenomena at close range, will leave the busses at the mouth of Mill D South Fork, proceed up that fork on foot, thence along a high divide, and rejoin the main party in the pass between Cottonwood and Little Cottonwood Canyons.

[36] Half a mile (0.8 kilometer) up South Fork the abundant great blocks of fossiliferous Madison limestone, many of which look like outcrops, are part of the moraine of the South Fork glacier, which caused a diversion of the stream to the west. Northward, across Cottonwood Creek, there are prominent ledges of Thaynes limestone broken by small faults. The great Silver Fork fault passes up the gulch east of these ledges; the rocks just east of the fault here belong to the Madison limestone. East of this point there are good exposures of Weber quartzite and underlying cherty limestone, both Pennsylvanian, which rest unconformably on Brazer (upper Mississippian) limestone containing large cone corals; a conglomerate at the base of the Pennsylvanian contains pebbles of the Brazer limestone.

[37] Montreal Spring may contain a large part of the dry-weather run-off from the main headwater basin of Mill D South Fork. The stream draining this basin flows into a sink hole south of Montreal Hill, and most of it probably flows through the hill by way of a fissure in limestone.

Northwest of the hill is a fine exposure of the Alta overthrust, which here brings Cambrian quartzite over Cambrian shale. The drag folds in the shale indicate that the upper block moved relatively eastward; the original dip of the thrust plane, therefore, was probably westward, though it is now eastward as a result of later movement. Steep faults, at least one of which is later than the overthrust, are visible on the same slope.

[38] The Cardiff mine has been the chief producer of the Cottonwood districts in recent years. The main buildings are on a block of Madison limestone bounded on the east and west by steep faults, both having the downthrow on the east. The deep mine workings are east of both these faults. The quartzite that there forms the surface has been thrust over limestone, and the main ore bodies have replaced the shattered limestone along thrust planes.

On the steep east wall of the canyon at least two higher overthrusts come to the surface; these cause a repetition of a thin

but conspicuous bed of whitish limestone in the lower part of the Madison.

To the southwest, in the strongly glaciated head of the canyon, the Cambrian quartzite is extensively exposed, and it is underlain by dark rusty tillite and varved argillite (pre-Cambrian or Cambrian).

[39] In the pass from the head of Mill D South Fork to Davenport Hill the country rock is the ancient tillite thrust over Cambrian quartzite, which normally overlies it. The route northeastward to the 10,523-foot (3,207-meter) peak at the south end of Reade and Benson Ridge passes over tillite and Cambrian quartzite, shale, and limestone, which, though cut by several thrusts and other faults, dip eastward in what is broadly their normal sequence.

This summit is a commanding viewpoint. Northeastward from it, across Days Fork, are exposures of Weber quartzite and underlying Carboniferous limestone, shale, and sandstone. Mount Baldy, to the south-southeast, across Little Cottonwood Canyon, at the head of the glaciated hanging valley Collins Gulch, consists of Cambrian quartzite which is thrust over the Madison limestone on its western slope. Within a mile (1.6 kilometers) west from Mount Baldy are exposed the greater part of the Madison and of the Cambrian, the tillite (which is tapering southward), pre-Cambrian quartzite and argillite below the tillite, and some of the intrusive Little Cottonwood quartz monzonite. The Twin Peaks, just west of south, are the highest points in the district (11,319 feet, or 3,450 meters). To the south-southeast, at the base of the opposite slope, is the South Hecla mine, also in the Alta thrust zone. On the slope east of it there are four or five higher thrusts, partly overturned.

[40] All along the crest from Reade and Benson Ridge to Davenport Hill the dip is persistently eastward. The rocks first crossed are sparsely fossiliferous Middle Cambrian limestones, here having their maximum thickness. To the east are good exposures of Madison limestone, cut by several rather small nearly north-south faults. The Madison contains many fossils, and on the hill between the heads of Days Fork and Silver Fork are large coral colonies.

The west slope of Davenport Hill consists of upper Mississippian limestone interbedded with sandstone. A breccia marks the position of the Snow fault.

[41] The Silver Fork fault crosses the summit of Davenport Hill and brings Carboniferous on the west against Cambrian limestone on the east. This Cambrian, only 200 or 300 feet (61 to 91 meters) below, is thrust over Mississippian limestone by what may be the Alta overthrust, brought to view again by relative upward movement on the east side of the Silver Fork fault.

From Davenport Hill, looking southward, there is an excellent view of the great cirque at the head of Little Cottonwood Creek. The Devils Castle is built of Madison limestone with low east dips; an overthrust nearly parallel to the bedding loops around the knob east of it. The path of a landslide a mile long, originating on the face of the Devils Castle, is marked by huge blocks of limestone. The Silver Fork fault passes along the west slope of the basin, where it cuts off the Alta granodiorite and a group of granodiorite dikes. On the spur just across City Rock Gulch from Davenport Hill the granodiorite cuts across Cambrian quartzite and shale, overlain by basal Carboniferous. Here the pre-Mississippian erosion wholly removed the Cambrian limestone, which, however, reappears not far to the south and thickens toward the Devils Castle.

The south slope of the ridge that has been followed is riddled with excavations, mostly tunnels, made in mining and prospecting. Some of the once productive mines, named in order from west to east, are the Rexall, Columbus, Flagstaff, and Emma. Across the basin northeast of Davenport Hill is the shaft of the old Prince of Wales mine, and on the slope to the southeast are the Michigan-Utah and other workings.

[42] The route leaves the crest and goes along the mountain side southeastward toward the pass between Alta and Silver Lake. On the slope between Davenport Hill and the pass is a closely healed thrust contact between Cambrian and Carboniferous limestones. Igneous metamorphism has here caused abundant formation of tremolite, forsterite, and brucite in the limestones, and its effects are still more conspicuous in calcareous shales and impure limestones, which contain garnet, vesuvianite, and other metamorphic silicates. On the contact with the granodiorite stock are a few masses of heavy minerals, including magnetite, ludwigite, pyrite, and chalcopyrite.

The slope is traversed by many northeasterly fissures; some of these are ore channels, and some contain dikes. The dikes are chiefly of quartz diorite porphyry or granodiorite porphyry, but one is of soda granite porphyry. Nearly all but the last mentioned have undergone an alteration that has greatly increased their lime content.

Near the trail toward Silver Lake many details of the main crosscutting intrusive contact are exposed. From the saddle at the head of Solitude Fork there is an excellent view of the north side of Cottonwood Canyon, with its simple structure, well brought out by vegetation, and subdued topography. Southwest of this viewpoint is a fine hanging cirque in granodiorite.

The spur east of Solitude Fork is skirted by a great lateral moraine.

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Excursion 6.—MOUNT TIMPANOGOS

By Murray O. Hayes

The route of the Timpanogos excursion follows the main highway south along the Jordan Valley, across the Traverse Mountain salient, and around the prominent embayment in the Wasatch front to the settlement of American Fork, thence turns east up the canyon of American Fork and along a high mountain road encircling Mount Timpanogos, the highest peak in the Wasatch Range, 11,957 feet (3,645 meters) above sea level, and descends southward into Provo Canyon, which it follows down west to Provo. (See pl. 10, *A*.)

A. FACET OF THE WASATCH ESCARPMENT NORTH OF PROVO, AT ROCK CANYON

Timpanogos Peak in the distance. From U. S. Geol. Survey Prof. Paper 153, pl. 20, *B*, 1928.

B. DINOSAUR BONES IN WALL OF QUARRY

Vertical femur in center is 5½ feet (1.67 meters) long.

A short excursion is made from Provo to the base of the Wasatch Range at the mouth of Rock Canyon to view an exposure showing deformation along the Wasatch front.

Mount Timpanogos is characteristic of the southern part of the Wasatch Range, which extends from the Cottonwood stock to Mount Nebo, a distance of some 60 miles (97 kilometers). This part differs from the sections north of it in that here the front is more abrupt to a great height and shows less evidence of older topography.

Mount Timpanogos is on the east side of the northern part of Utah Valley. The Timpanogos loop road goes from American Fork Canyon across the back of the mountain, reaching an altitude of about 8,000 feet (2,400 meters).

The loop may be reached from the State highway running south from Salt Lake City by turning east some 2 miles (3.2 kilometers) south of the point of the mountain, 22 miles (35 kilometers) south of the city. This road goes through the southern edge of the village of Alpine to the American Fork Canyon. From the south the loop may be reached by going from either Provo or Orem up through Provo Canyon to the summer camp resort known as Wildwood, then turning left up the North Fork.

The mouth of the American Fork Canyon is in Mississippian carbonaceous limestones. These soon give way to quartzite and argillaceous schists of Algonkian age; possibly some of the schists are Cambrian. The schists and quartzites are well shown in the vicinity of Timpanogos Cave.

Some little distance above the cave camp ground 1,000 to 1,500 feet (305 to 457 meters) of Cambrian limestones and dolomites are encountered. These beds are sparsely fossiliferous.

In this area the Mississippian lies directly on the Cambrian without notable angular unconformity. After leaving the Cambrian strata in this canyon the route for the remainder of the trip leads over Carboniferous rocks, except that from the divide between the two canyons to a point near the mouth of North Fork, or Timpanogos Canyon, there is a superficial cover of glacial débris.

Timpanogos Cave is the result of faulting and subsequent solution along the fault surface in the soft Mississippian limestone. Some of its stalactitic forms are of exquisite daintiness and intricacy.

From the point of the mountain Timpanogos appears to be a ridge of knifelike sharpness. As the higher reaches of American Fork Canyon are attained it is seen that this appearance is due in part to the extensive removal of material from the back of

the mountain by glacial activity, there being a number of large, well-defined cirques.

The structure and stratigraphy of the mountain explain, at least in part, why the ice work was so effective.

The rocks in Mount Timpanogos are Mississippian and Pennsylvanian limestones and quartzites. The lower part is almost entirely made up of the Mississippian, in general soft and highly carbonaceous; the upper part consists of limestones, carbonaceous and highly cherty at the top of the ridge, and quartzites, the proportion of quartzite increasing with the altitude.

The beds have a gentle inclination to the northeast, and the drainage naturally was of the consequent type and cut canyons down the slope. With increasing frigidity the snow accumulated in these ravines and readily plucked great masses from the well-stratified and little resistant rocks.

This mountain is part of the upthrown block along the Wasatch fault. On its western face the fault scarp reaches a height of 7,500 feet (2,286 meters) above the valley, without foothills of consequence.

The acuteness of the ridge is not entirely due to erosion by ice and water. There are several faults on the back of the mountain, with downthrow to the east, one of which has a vertical displacement of 2,000 feet (610 meters); the ridge is thus in the nature of a horst.

A considerable portion of the road on the back of Mount Timpanogos is over glacial deposits. There are numerous well-developed moraines, especially prominent and noticeable in the vicinity of the Aspen Grove camp ground and the summer school buildings of Brigham Young University.

All the exposures in Provo Canyon are Carboniferous, those near the road being mainly Mississippian.

At the mouth of Rock Canyon in the base of the Wasatch front just east of Provo exposures of Mississippian limestone and of Wasatch faults, with evidence of recent movement (100),[16] can be studied.

In Rock Canyon, northeast of Provo, the basal sandstone of the Mississippian can be seen by going up to the first small longitudinal valley on the north side of the canyon and then back down the canyon a few feet. It is from 2 to 10 feet (0.6 to 3 meters) thick and ranges from fine sand to small pebbles and from loosely consolidated sand to almost a quartzite. Spirifers have been found in it by the writer.

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[16] See bibliography on p. 101.

The strike valleys that run from Rock Canyon to Provo Canyon are cut in very soft shales that lie between the resistant limestone strata which form the ridges. Faulting has had very little to do with their formation; there is good paleontologic and stratigraphic evidence to show that there is no more than minor displacement along these valleys.

The Columbia steel plant, a subsidiary of the United States Steel Corporation, comprising blast furnaces and by-product coke ovens, is situated at Ironton, just south of Provo.

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Excursion 7.—TINTIC MINING DISTRICT

By Paul Billingsley [17]

GEOGRAPHY

The Tintic mining district occupies both slopes of the East Tintic Mountains, about 65 miles (105 kilometers) due south of Salt Lake City. It embraces a mineralized area of about 30 square miles (78 square kilometers), one-fourth of which has produced fully 90 per cent of the district's wealth. Within the district are the towns of Eureka, Dividend, Mammoth, and Silver City, all of which are served by one or more railroads, as well as by good automobile highways.

The East Tintic Mountains form one of the easternmost ranges of the Basin and Range province. They have a general north-south trend. As in most of the Basin Ranges, their topographic relief is pronounced. Their east base, along the top of the Bonneville gravel beds of Goshen Valley, has an altitude of 5,100 feet (1,554 meters); their west base, along the alluvium-filled Tintic Valley, 6,100 feet (1,859 meters); and their highest peaks 8,100 feet (2,469 meters).

HISTORY

The existence of ores of silver, lead, gold, and copper in this area was determined in the early 1870's, but the last decade of intensive development has proved that the ores are far more widely distributed than was formerly suspected.

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[17] The sections on geography, sedimentary rocks, and igneous rocks were written by G. W. Crane.

The district, as shown on Plate 11, has a three-part pattern, the southern portion consisting of intrusive monzonite and rhyolite porphyry and effusive rocks, the central portion of exposed limestones, and the northern and northeastern portion of limestones blanketed by rhyolite flows. This pattern of formations has controlled the discovery and exploitation of the ores.

The earliest discoveries, in 1869, were veins in the monzonite and quartz porphyry (Swansea rhyolite). The vein outcrops were prominent, with some ore at the surface, but the aggregate yield of these vein mines, largely from the Swansea vein in the quartz porphyry, has not exceeded $10,000,000.

There were very few outcrops of ore in the central area of limestone, but these few were early discovered and followed down into large persistent ore channels. The Mammoth outcrop, near the southern edge of the limestone, was found in 1872, and the mine rapidly developed into one of the largest of the early producers. The Eureka Hill outcrop, about 1½ miles (2.4 kilometers) farther northwest, was successfully developed a few years later and led to the discovery of the ore bodies of the Eureka Hill, Bullion Beck, and Centennial Eureka mines. By 1886 this Eureka Hill-Centennial Eureka area was the dominant producing center of the district.

The third ore outcrop in limestone, about 1¼ miles (2 kilometers) to the east, was found and developed at the same time as the Eureka Hill outcrop and led to the discovery of the ore bodies of the Humbug, Uncle Sam, and Godiva mines. During this first stage of its career, from 1869 to 1886, the district produced ore to a total value of about $9,000,000.

The next 20 years saw a great expansion of development at depth along the ore channels thus discovered. The Bullion Beck ore runs led into the Gemini mine, the Centennial into the Grand Central (lower levels), the Uncle Sam into the Yankee, the Mammoth into the Grand Central (upper levels), etc. New deposits of lesser importance were also discovered, mainly within the metamorphosed rim of the limestone along the monzonite contact. This group includes the Ajax, Star, Lower Mammoth, and Northern Spy. A small outcrop of ore half a mile (0.8 kilometer) east of the Eureka Hill led to the discovery of the Eagle and Blue Bell deposits. This period saw the culmination and decline of the Centennial Eureka, one of the three greatest mines of the district and the only one of these deposits to be discovered prior to 1910. From 1886 to 1905 the district produced $77,000,000.

In 1905 the final great discovery in the central limestone area was made. A new major ore channel was found by Jesse Knight, of Provo, in the eastern part of the Beck Tunnel mine. This channel, only 200 to 300 feet (61 to 91 meters) below the

surface but entirely devoid of outcrops, was followed southward through the Colorado and Sioux mines into the Iron Blossom mine. It became immediately the principal center of production in the district and raised the annual yield from $5,000,000 to over $8,000,000. In the seven years 1906 to 1912 the district produced $54,000,000.

The discovery of the Chief Consolidated deposit beneath the rhyolite capping began a new stage in the history of the Tintic district. The rhyolite flows which lap around the north end of the central area of limestone and spread over a wide region to the east are premineral in age and show certain phenomena indicative of ore below; but these facts had not been heeded during the first 40 years of mining in the district.

In 1909 the Chief Consolidated shaft was sunk through the rhyolite north of the mine to crosscut the underlying limestone in search of the northerly extension of the Eagle and Blue Bell ore channel. The extension was found in 1910—one branch of it on the 1,000-foot (305-meter) level and the main part on the 1,400-foot (427-meter) level. The Chief Consolidated mine in fact proved to contain the main center from which the Eagle and Blue channels were merely extensions. It has produced more than $30,000,000 during the last 20 years.

In 1907 the Tintic Standard No. 1 shaft was sunk through altered rhyolite, flanked by mineralized limestone hills, more than 2 miles (3.2 kilometers) east of any important mines in the district. Development beneath the rhyolite was impeded by heat and gas, which were unique in the experience of the district, but in 1916 a winze from the 1,000-foot (305-meter) level broke into the great ore bodies of what has become known as the "Tintic Standard pothole." This mine has already produced $77,000,000 and is far from exhaustion. Coming from a compact area of less than 20 acres (8 hectares), this production marks the Tintic Standard pothole as one of the greatest ore centers in the West.

This success stimulated prospecting below the rhyolite, which has been aided by the use of geologic criteria obtained in the Tintic Standard mine. Alteration phenomena on the surface are widespread, but structure beneath the rhyolite is concealed and must be slowly disclosed by underground exploration. Under these conditions exploration has gone forward by successive steps. The North Lily deposit, half a mile (0.8 kilometer) northwest of the Tintic Standard, was discovered in 1927; the adjoining Eureka Lilly in 1928, and the Eureka Standard, 1 mile (1.6 kilometers) south of the Tintic Standard, in 1928. Work is now moving on beyond these mines into more remote

areas of promise, but the deep exploration is still in its early stages.

The latest period of the Tintic district's history, from 1916 to 1931, has been the most productive. The yield has been over $205,000,000, or nearly two-thirds of the total output, which is estimated at about $345,000,000. Approximately half of this yield has come from silver, one-quarter from lead, and one-eighth each from gold and copper. (See fig. 12.)

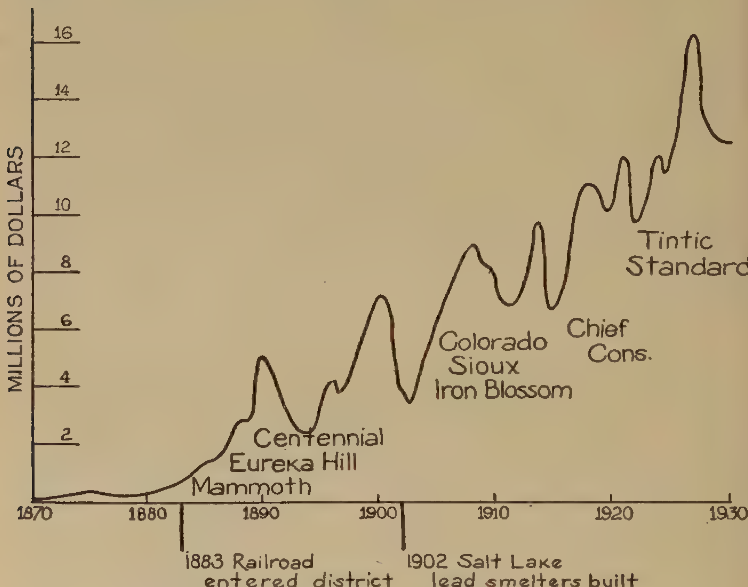


FIGURE 12.—Production chart, Tintic mining district

GENERAL GEOLOGY

The rocks of the Tintic district (see pl. 12) consist of about 13,000 feet (4,000 meters) of Paleozoic sediments, including quartzite, limestone, and shale, overlain unconformably and intruded by igneous rocks of Tertiary age. The sedimentary rocks are folded into a broad northward-pitching syncline with a vertical western limb and a gently dipping eastern limb that passes into a low anticline in the eastern part of the district. The folding was accompanied by much transverse faulting, largely of the lateral thrust type. Some of these faults are very large, the horizontal displacement reaching 2,000 feet (610 meters). Differential movement between beds during folding has caused faults

nearly parallel to the bedding and therefore difficult of observation on the surface. Most of the faulting accompanied or closely followed Laramide and later folding, and many faults that were not completely healed have had an important bearing upon the localization of the mineral deposits; but there are also faults that are of late Tertiary age and younger than the period of ore formation. Faults of this order are usually small, are all normal, and rarely show either lateral thrust or recementation. Relatively few of the postmineral faults have greatly interfered with the development of the district. They were probably formed at the same time as the large faults along which the Basin Ranges were developed.

SEDIMENTARY ROCKS

The sedimentary rocks range in age from Lower Cambrian to late Mississippian, with unconformities at the top of the Cambrian and at the base of the Mississippian. Within the limestones alone 15 divisions have been recognized on lithologic grounds because of their importance in solving structural and stratigraphic problems and their great differences in mineral-bearing tendencies.

Lower Cambrian.—The Tintic quartzite, the lowest member of the stratigraphic series, has an estimated thickness of 5,000 to 7,000 feet (1,524 to 2,134 meters). It is for the most part a grayish-white to pale-pink fine to coarse grained rock, consisting almost wholly of quartz. Though in part conspicuously massive, it is commonly well bedded and in a few places has thin shaly partings and thin conglomerate beds.

No fossils have been found within the Tintic quartzite, and its correlation as Lower Cambrian is based upon stratigraphic position alone. Recent discoveries of gold-bearing fissure veins in the quartzite in the eastern part of the district has enhanced the economic possibilities of the formation.

Middle Cambrian.—The Middle Cambrian includes the Ophir, Teutonic, Dagmar, Herkimer, Bluebird, and Cole Canyon formations.

The Ophir formation consists of a series of interbedded shales, limestones, and quartzitic slates, 358 feet (109 meters) in thickness, which lie conformably upon the Tintic quartzite. The limestone members of the Ophir formation are characteristically nondolomitic, fine grained, and subcrystalline. Economically they are very important in that they harbor the larger portion of the ore bodies in the Tintic Standard, Eureka Lilly, and North Lily mines.

The Teutonic formation on Quartzite Ridge consists of 420 feet (128 meters) of limestone and dolomite, which rest conformably

upon the upper soft shale member of the Ophir formation. The upper 20 feet (6 meters) of the formation consists of dark-blue dolomite, the earliest occurrence of dolomite in the Tintic section.

The Dagmar formation consists of about 79 feet (24 meters) of white-weathering fine-grained argillaceous dolomitic limestone. The entire formation is nearly uniform in appearance and, lying between thick dark-gray to blue dolomites, probably forms the most distinctive horizon marker in the district.

The Herkimer formation consists of 225 to 270 feet (69 to 82 meters) of impure blue limestone mottled and striped with yellowish argillaceous material. No important ore deposits are known to occur in this formation.

The Bluebird formation, ranging from 175 to 200 feet (53 to 61 meters) in thickness, contains the lowest of the "vermicular dolomites," so called because of the prevalence of many short white rodlike calcareous inclusions.

The Cole Canyon dolomite, 600 feet (183 meters) in thickness, consists of a succession of 29 or more alternating light-gray to white and dark bluish-gray layers ranging from 2 to 94 feet (0.6 to 29 meters) in thickness. On the evidence of fossils, identified as *Obolus mcconnelli*, this dolomite was provisionally assigned by Walcott to the Middle Cambrian.

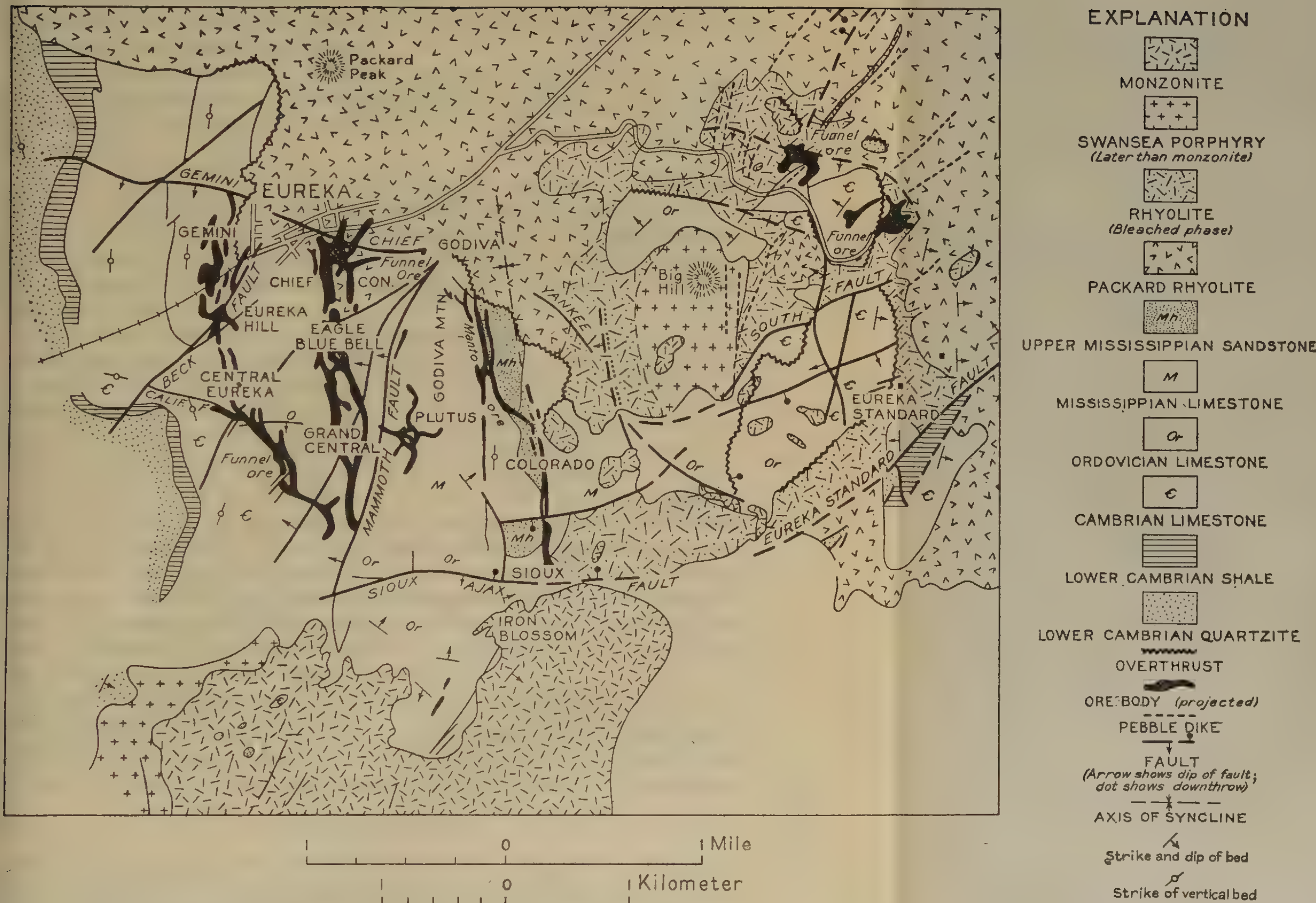
Upper Cambrian (?).—The Opex dolomite is composed largely of thin beds of impure dolomite and shale. In the Centennial Eureka mine it has an average thickness of 516 feet (157 meters).

Unconformity at top of Cambrian.—Although there is no angular discordance between the Cambrian and Ordovician, the presence of rounded pebbles of quartzite and limestone in the conglomerate beds at the base of the Ajax limestone, of lower Ordovician age, led Loughlin to infer that the Cambrian emerged from the sea near the beginning of Ordovician time. The Opohonga limestone, which overlies the Ajax, contains many intraformational conglomerates, but rounded pebbles of Cambrian rocks have been found with them in a few places and imply that Cambrian strata were exposed to erosion during a considerable part of lower Ordovician time.

Ordovician.—The Ajax limestone consists of about 610 feet of cherty, magnesian limestone and dolomite, with a distinctive creamy-white bed, called the Emerald dolomite member, in its middle part. This bed is very persistent, and, as its color is characteristic of both fresh and weathered surfaces, it has been an excellent guide in mapping. Much of the ore in the Gemini ore channel was formed by replacement of the Ajax limestone, and this formation therefore ranks among the more favorable ore bearers of the district.

GENERAL GEOLOGIC MAP OF TINTIC DISTRICT

From U. S. Geol. Survey Prof. Paper 107, pl. 1, 1919.



GEOLOGIC MAP OF PART OF TINTIC DISTRICT, SHOWING ORE BODIES

The Opohonga limestone consists of 800 to 1,000 feet (244 to 305 meters) of yellowish-gray, striped argillaceous limestone with many beds of intraformational conglomerate, a few of which contain rounded pebbles of underlying formations. Underground this limestone appears light gray and thin bedded, with a few thin layers and partings of gray shale.

The Bluebell dolomite has a thickness of 894 feet (272 meters). As a whole it consists of a series of alternating beds that weather light gray and dark bluish gray.

Devonian.—The Pinyon Peak limestone, of Upper Devonian age, has been found only on the east slope of Pinyon Peak. It is 150 feet (46 meters) in thickness and resembles the Opohonga limestone.

Mississippian.—The Victoria formation consists of 209 feet (64 meters) of thin-bedded impure dolomite interspaced with a dozen or more beds of quartzitic sandstone, which, though constituting only 10 per cent of the formation, crop out prominently. The formation marks an unconformity at the base of the Mississippian.

The Gardner formation is characterized by a variety of dolomite beds alternating with nearly pure limestone and capped by a thick bed of black cherty carbonaceous shale. It is 815 feet (248 meters) thick. White limestone, sugary dolomite, and locally blue flaky limestone beds in it are replaced by ore. The Gardner formation is rich in lower Mississippian fossils.

The Pine Canyon limestone, 732 feet (223 meters) thick, is composed mainly of alternating light and dark colored thick beds of cherty limestone. The upper half contains many arenaceous beds that mark a gradation into the overlying Humbug formation, which is of upper Mississippian age. An 82-foot (25-meter) bed of coarsely crystalline, nearly pure light-gray limestone 420 feet (128 meters) above the base has been replaced by ore bodies of the Colorado or Iron Blossom channel.

The Humbug formation consists of about 224 feet (68 meters) of sandstone, shale, and limestone. The beds here exposed form only the lower part of a much thicker formation of similar strata which is completely exposed in the Mercur district, to the north.

IGNEOUS ROCKS

The greater part of the Tintic district is covered by Tertiary igneous rocks. They are mostly effusive but include a few necks and stocks and many dikes. The effusive rocks, named in general order of eruption, are rhyolite, latite tuff and breccia, and latite flows. They overlie the eroded sedimentary rocks, but the writer believes that the rhyolite was affected by a late stage of

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folding and thrust faulting that preceded the eruption of the latite group. The intrusive rocks, other than rhyolite, are necks and stocks of latite porphyry and monzonite porphyry, some of which are clearly contemporaneous with certain of the flows; the main monzonite stock of the district and its related minor stocks and dikes; and finally some basalt dikes that are not present in the more mineralized areas. Some rhyolite dikes are clearly related to the rhyolite flows and are therefore older than the monzonite. The largest intrusive mass of rhyolite porphyry, called the Swansea rhyolite, and related dikes were also described in the United States Geological Survey's report on the district (103, p. 48)[18] as older than the main monzonite stock, but the writer's study of this porphyry has convinced him that it is intrusive into the monzonite.

The monzonite and monzonite porphyry occur as a group of stocks and plugs, mostly within an area 5 miles (8 kilometers) long and 3 miles (4.8 kilometers) wide that extends southward from Mammoth to Volcano Ridge. Smaller plugs and dikes of monzonite porphyry cut the sedimentary and overlying volcanic rocks at intervals along a north-northeasterly zone from Sioux Pass to Homansville Canyon. These as well as the main monzonite stock south of Mammoth are bordered in part by contact-metamorphic limestones and are closely associated with valuable ore deposits. The main stock contains many inclusions of quartzite, shale, and metamorphic limestone.

STRUCTURAL HISTORY

The present structure of the district has resulted from several stages of deformation and volcanism, which will be summarized in historical order. (See fig. 13.) Before the beginning of Tertiary volcanism the sedimentary rocks of the district had been folded into a main elliptical synclinal basin, bordered on the east by a minor anticline, and had been deeply eroded. The rim of this syncline consisted of Cambrian quartzite. Its major axis extended northeastward for about 7 miles (11 kilometers), and its maximum width was 4 miles (6.4 kilometers). The writer correlates this folding with the Laramide revolution.

The syncline was broken by northwest faults prior to Tertiary volcanism. These faults have south dips and show an offsetting of their north sides toward the northwest. Their individual displacements amount to 1,000 feet (305 meters) or more and are mainly horizontal, but the southwest walls have dropped somewhat. These faults became sites for volcanic vents, through which rhyolitic and allied lavas reached the surface, forming a

[18] Numbers in parentheses refer to bibliography, p. 124.

series of flows about 2,000 feet (610 meters) thick in the center of the basin, from which they overflowed to the east in thinner fringes.

The later Tertiary Cordilleran compression and overthrusting superimposed upon this simple structure the features which are now most conspicuous and which have determined the pattern of the ore deposition. Stated briefly, this Cordilleran movement pushed in the western limb of the syncline until it assumed a vertical or slightly overturned attitude. The necessary adjustments between this new steep limb and the gentle eastern limb made wedge-shaped segments of intense crumpling. The push from the west had some effect even on the eastern limb, however, producing minor overturned crumples sufficient to break the

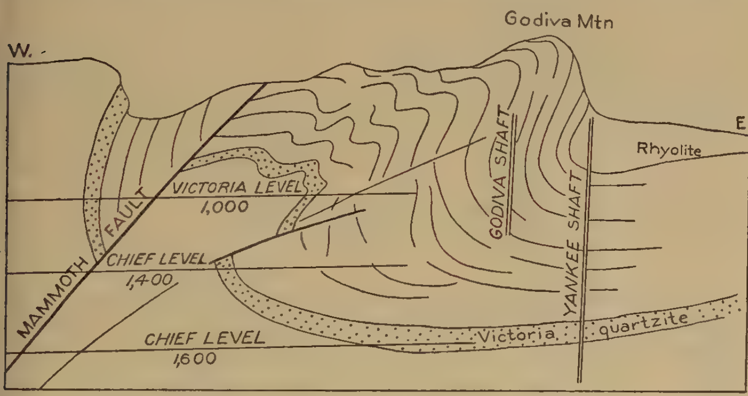

FIGURE 13.—Generalized section of the Tintic district, emphasizing fundamental structural features, some of which are not revealed at the surface

rhyolite blanket and force up masses of the underlying limestone which are now exposed as eastward-facing cusps.

Monzonite intrusion closely followed this period of thrusting. Northward extensions from the principal stock follow the main thrust crumples of the eastern limb intermittently for several miles. A final more acidic intrusive, the Swansea rhyolite or quartz porphyry, occurs along the western margin of the monzonite. A highly altered stock to the northeast, the alunitized porphyry of Big Hill, may also represent this final acidic stage of intrusion.

The ore solutions followed the Swansea quartz porphyry, dikes of which point like finger tips toward the ore foci. The solutions evidently passed through deep northeast channels until a special structural condition permitted them to escape upward through an ore focus into the crumpled rock above.

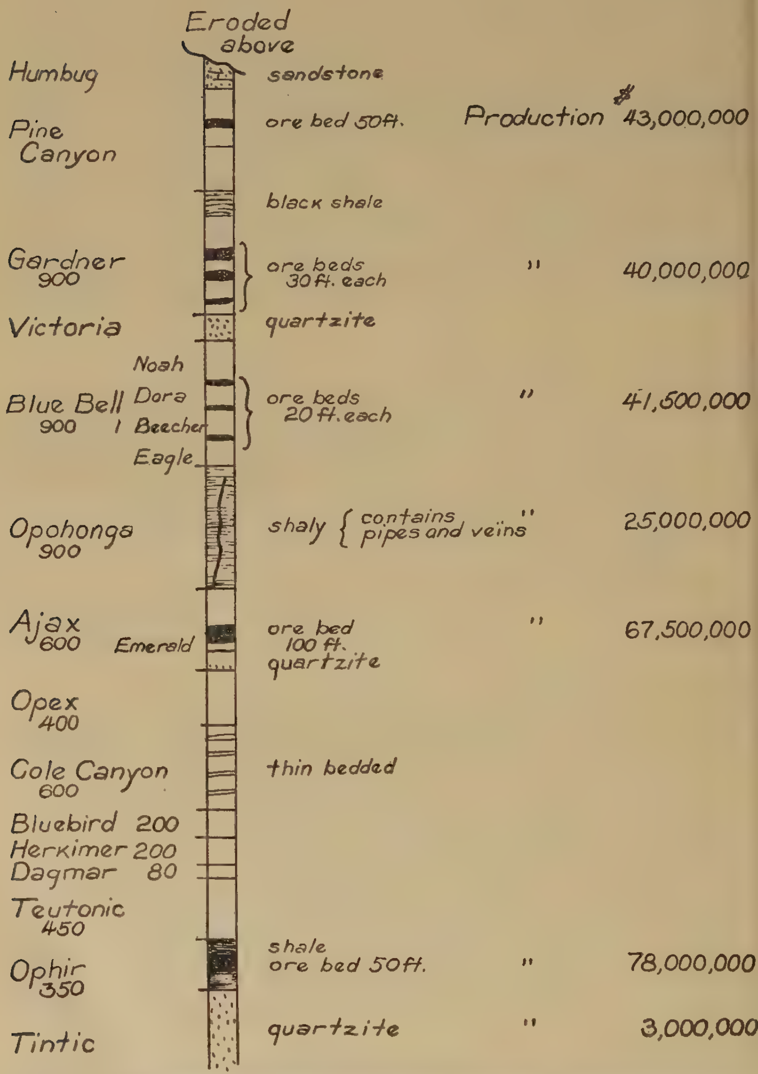

FIGURE 14.—Stratigraphic column of the Tintic district. Names of formations at left; figures indicate thickness in feet

A feature that has greatly influenced the placing of the ore bodies is the shallowness of these breaks and crumples. Every shaft in the district that extends from 1,000 to 2,000 feet (305 to 610 meters) below the surface (5,000 feet (1,524 meters) above sea level) shows a simplification of the structure. Not only do the beds dip more gently and regularly, but the faults, which may have displacements of 1,000 feet (305 meters) at the surface, usually dwindle almost to nothing. The movement involved was not up and down but horizontal and is confined to a surface layer only 2,000 feet (610 meters) thick. This movement was intense in the western blocks, which contained the early mines of the district; it was slight in the central block of gentle dip but was transferred with reduced intensity by the push of this central block to the eastern limb, which contains the most recently developed mines of the district.

So far in the history of the district the large ore deposits have been strictly confined to the shallow layer of crumpling; the amount of ore has been in proportion to the amount of crumpling; and the deepest development has found only small ore shoots in northeast veins.

GEOLOGY OF ORE DEPOSITS

RELATION OF ORE TO FORMATIONS

In the detailed columnar section (fig. 14) there are shown nine beds with an aggregate thickness of 350 feet (107 meters) that carry almost all the ore.

Because of the synclinal structure of the district, combined with the shallowness of the mineralization, the stratigraphically lower ore beds are found in the marginal ore foci, and the higher ones in the more central foci. (See fig. 15.) The following table gives the productive formation at each focus and the gross production.

	Formation	Production
Tintic Standard focus: Tintic Standard	Ophir	$72,000,000
North Lily focus: North Lily, Eureka Lilly.	do	6,000,000
Centennial Eureka focus: Centennial, lower Grand Central.	Ajax	55,000,000
Beck-Gemini focus:		
Eureka Hill	Ajax	12,500,000
Bullion Beck, Gemini	Blue Bell	12,500,000
Mammoth focus:		
Mammoth pipe	Opohonga	25,000,000
Upper Grand Central	Blue Bell	4,000,000

	Formation	Production
Chief Consolidated focus:		
Chief Consolidated mine	Gardner	$40,000,000
Eagle and Blue Bell	Blue Bell	20,000,000
Iron Blossom focus:		
Beck, Colorado, Sioux	Pine Canyon	
Iron Blossom	Gardner	27,000,000
Plutus [a]	Blue Bell	5,000,000
Godiva [a]	Pine Canyon	16,000,000
Eureka Standard	Vein in Tintic quartzite.	2,000,000
Swansea, Sunbeam, etc	Veins in igneous rock	10,000,000

[a] "Runs" or "channels" from undiscovered foci.

FIGURE 15.—Ore centers of the Tintic district

RELATION OF ORE TO STRUCTURE

The ore bodies have forms somewhat resembling certain corals. They branch upward and outward from a "root" or "focus." The position of each "focus" and the direction of each branch depend upon local structural control. The structural features that are associated with the largest ore deposits are shown in the accompanying sketches.

Figure 16 shows the distortion of the Emerald dolomite near the productive bed in the Centennial Eureka and Grand Central mines. This sliced and overturned structure is characteristic of the southwestern wedge block in which these mines lie. Very similar structure is found in the Chief Consolidated mine (fig. 16), which lies near the northern point of this same block. The ore foci on the eastern limb are much like those of the Chief in structure. Figure 17 gives cross sections of the North Lily and Tintic Standard.

In each focus there is a sharp downward fold, which may be accentuated by faulting. Such a fold must greatly shatter the rock bent around its lower involution; and it seems certain that this development of downward-bent and shattered rock has been the commonest agency for the release of ore solutions from the deep channels.

Such structure, where the proper formations are involved, has afforded the foci through which ore has entered the crumpled rock. Almost all of the ore in the district is traced to one of seven such foci. Each of these has yielded a production ranging from $25,000,000 to $75,000,000, and taken together the seven account for nine-tenths of the district's total production of $345,000,000.

ORE FOCI

The seven main foci are fully explored by the workings from their roots to the tips of their branches or "runs." A study shows them to have common characteristics, which persist despite the variety of rocks in which they occur. These characteristics may be summarized as follows:

1. All occur at some specially crumpled or otherwise broken place along one of the old northwest faults, such as the East fissure in the Tintic Standard mine, the Chief-Gemini fault, or the Sioux-Ajax system.

2. At the bottom a system of northeasterly veins carries ore of lower grade in rock with gently dipping beds.

3. These veins extend up into the layer of crumpled ground, and where shale is present, as in the Mammoth, Tintic Standard, and North Lily, they change their shapes to pipes, through which the mineralization has vertically traversed the shale. If shale is absent the pipe phase is much less developed.

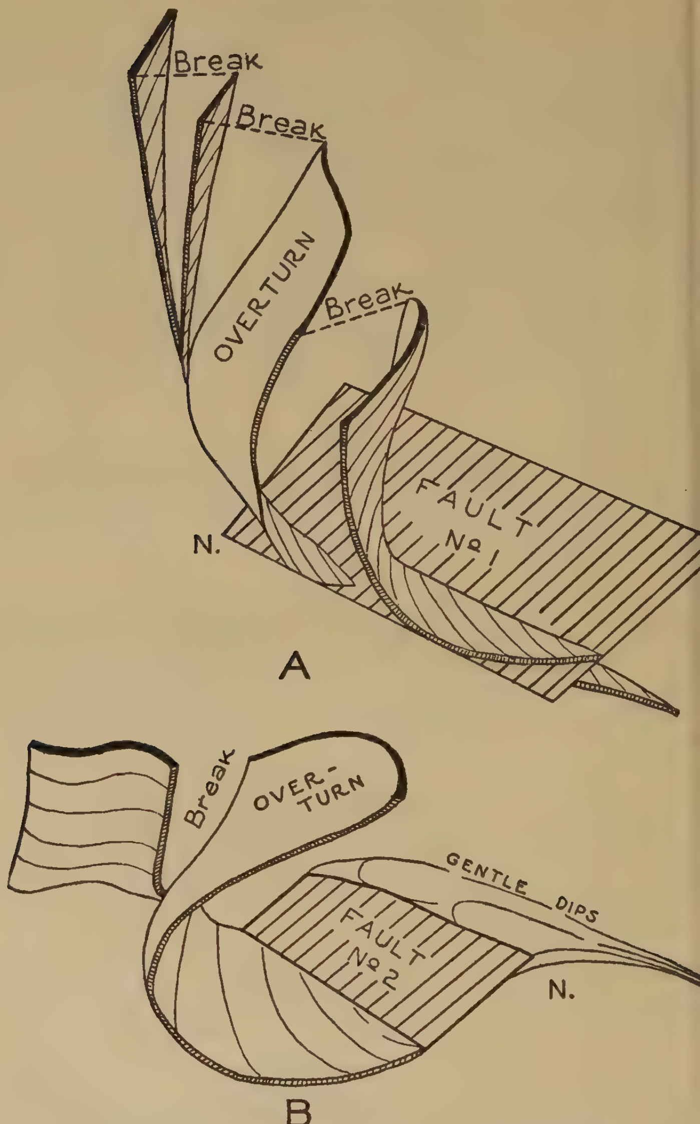

FIGURE 16.—Structure in the Centennial Eureka and Chief Consolidated mines
A, Centennial Eureka, distance from top to bottom about 2,200 feet (67
meters); B, Chief Consolidated, distance from top to bottom about 1,200 fee
(365 meters)

4. On reaching crumpled limestone, the pipe expands into the three-dimension ore bodies or "funnels" that have made the large volume of production of the district—the Centennial, Chief Consolidated, and Tintic Standard.

5. The main ore masses have marginal extensions, which radiate into every available channel. By far the largest of these

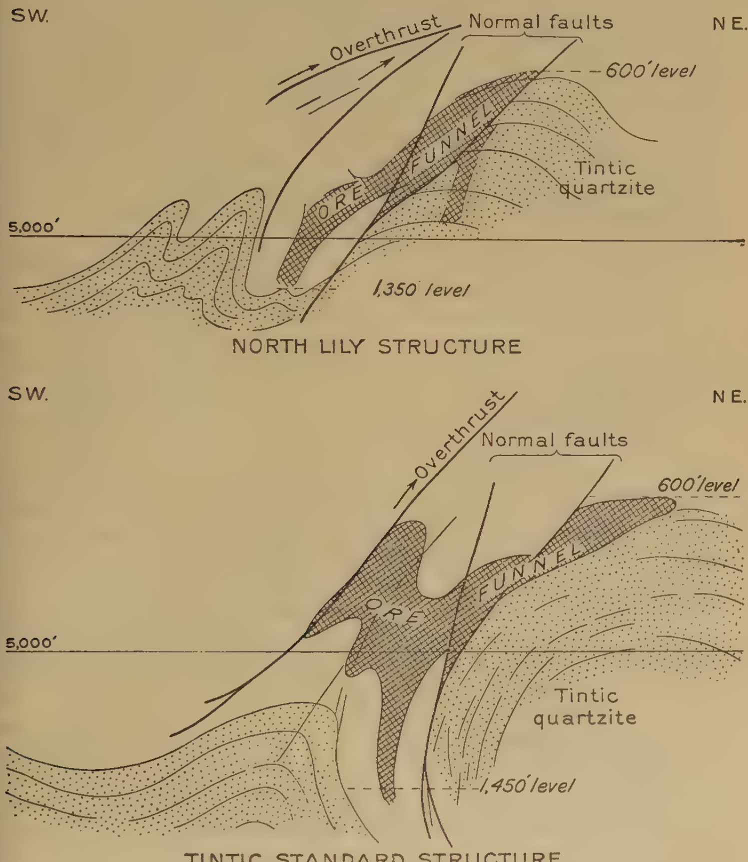

FIGURE 17.—Structure in the North Lily and Tintic Standard mines

channels are found along the flattish hinge or crease where a deep, gently dipping bed turns upward into the steep limbs of crumples. Other channels spread along the northwest faults, or along their intersections with favorable beds. Still others, of less size,

follow northeast faults or minor thrusts connected with the crumpling.

VERTICAL RANGE OF ORE DEPOSITION

Outcrops of ore in the district are few, even in the area of uncovered limestone, and are without exception on slopes of recent rapid erosion, so that it seems certain that at the time of ore deposition these also were below the surface.

The upper limits of ore deposition throughout the district are harmonious in respect to the probable surface at that time, which can be restored from remnants of a postrhyolite erosion surface. This forms a broad arch across the district, rising from 6,200 feet (1,890 meters) near the Tintic Standard to 8,000 feet (2,438 meters) on Godiva Mountain and descending to 7,300 feet (2,225 meters) on the western edge of the district.

The ore has upper limits at the following distances above sea level:

	Feet	Meters
Tintic Standard	5,400	1,646
North Lily	5,500	1,676
Iron Blossom	6,800	2,073
Godiva	7,500	2,286
Mammoth	7,000	2,134
Centennial	6,800	2,073
Eagle-Blue Bell	6,800	2,073
Beck-Gemini	6,400	1,951

These altitudes average about 700 feet (213 meters) below the old erosion surface and are believed to mark the top of ground water at the time of mineralization. Only an occasional squirt of the ore-bearing solutions got above these limits.

The lower limits of important ore deposition in the limestone are even sharper. Above these we find large deposits of silver, lead, gold, or copper ores. Below them are lean quartz veins carrying small amounts of these metals with considerable zinc. These lower limits are as follows:

	Feet	Meters
Tintic Standard	4,600	1,402
North Lily	4,800	1,463
Chief Consolidated	4,700	1,433
Mammoth	4,900	1,494
Grand Central	5,000	1,524
Centennial Eureka	5,000	1,524
Gemini	4,600	1,402

It seems probable that upon arriving at these levels the ore solutions were abruptly reduced in pressure by expansion into the wider openings of the shallow crumpled zone. The ores in the veins in monzonite or porphyry, where there are no large openings, retain the low-grade "root" characters up to much higher altitudes.

CHARACTER OF MINERALIZATION

The surge of mineralization that followed the final quartz porphyry intrusion and spread, under the limitations above indicated, into the favorable crumpled zones of the district, was composed of several phases:

1. Most widespread was dolomitization in the limestones, with allied alteration in the overlying rhyolite.

2. Somewhat more selective, but still far ranging and in large volume, was silicification. In the western areas this produced amorphous gray silica carrying tiny specks of lead and zinc sulphide; in East Tintic, similar silica with specks of pyrite and alunite also.

3. In East Tintic also occurred the peculiar canalized form of silicification that produced "pebble dikes." These have developed where hot silica mud has surged through broken rubbly quartzite and on up through the shale into fissures in the overlying limestones. Pebbles, predominantly of quartzite, rounded and with strong "onion-skin" exfoliation, have been carried along for thousands of feet in these pebble dikes. They are included within a matrix of amorphous silica, which may contain a little pyrite and barite also. Followed back toward their source, some pebble dikes show a transition of the groundmass material into fine glassy porphyry with flow lines around the pebbles.

4. The first metallic mineralization deposited quartz and barite, with small amounts of pyrite, tetrahedrite, enargite, galena, and sphalerite. This phase, which was relatively high in gold, formed the ore bodies of the Centennial Eureka, Grand Central, and Mammoth foci. It occurred also in the veins in the metamorphosed fringe of limestone, in the southern part of the Iron Blossom, in the Eureka Standard, and in parts of the Tintic Standard and North Lily foci. The ores of this phase are rich in gold and silver, have appreciable copper, and are low in lead. They form a southerly belt across the district.

5. The second stage of metallic mineralization was rich in lead and contained considerable zinc. It formed the ores of the Beck-Gemini, Chief Consolidated, Godiva, northern Iron Blossom, North Lily, and Tintic Standard foci, a northerly belt.

6. One widespread type of mineralization formed large oxidized jasperoid iron-manganese masses in the south-central part of the district. The largest of these, in the Dragon mine, lies directly against the main monzonite contact; others, in the Iron King mine, are adjacent to minor sheets of the monzonite; in the North Lily mine similar mineralized rock just above the ore body adjoins a monzonite sill. Presumably, therefore, this iron-manganese ore is a contact product of the monzonite

intrusive. It is cut, in the Dragon mine, by quartz-barite veins, which represent the earliest phase of the true ore mineralization.

Figure 18 gives the broad aspects of these variants of the mineralization.

FIGURE 18.—Features of mineralization in the Tintic district

TINTIC STANDARD MINE

Structural setting.—An understanding of the Tintic Standard ore occurrence involves a knowledge of the subrhyolite structure, the relationship of the ore bodies to that structure, and the indications as to the rhyolite surface afforded by such ore bodies.

Figure 19 shows the subrhyolite structure. It is obvious that there are conflicting structural trends. A northeasterly broad anticline is the earliest product of deformation, followed in order by a northwest fault (East fissure), northeast faults, and sharp

north-south crumples. The crumples are complete folds, with an overturned anticline to the west of a sharp syncline or involution. The final result is a complex pattern, in which the quartzite forms high ridges on the old axis and also along the anticlinal

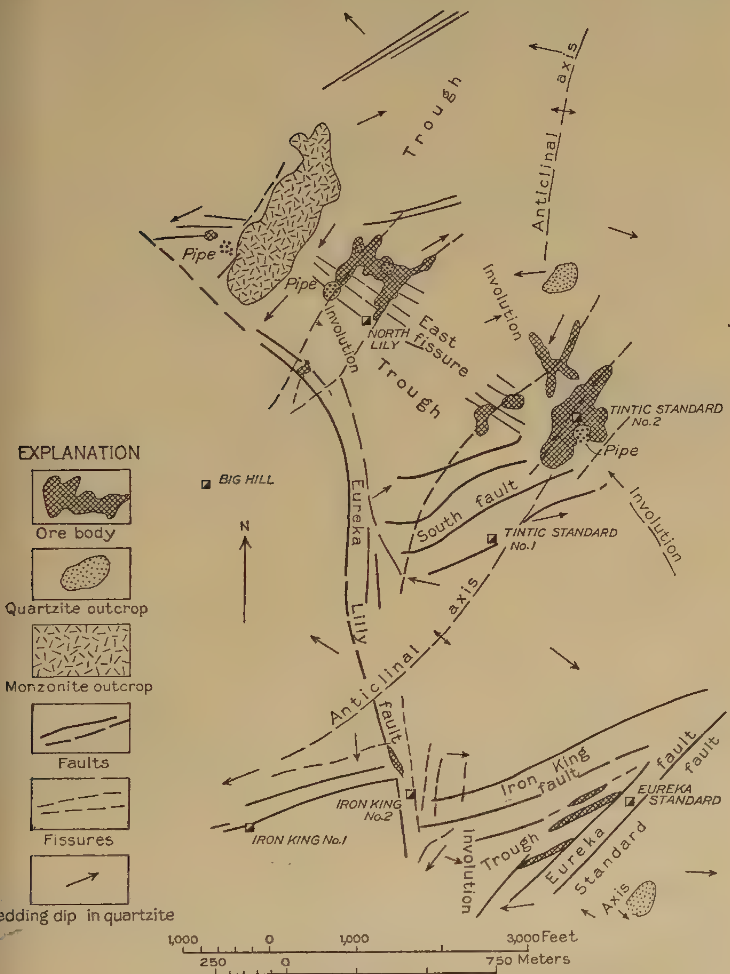

FIGURE 19.—Subrhyolite structure, East Tintic

ortions of the late crumples, while deep troughs are developed y the early faulting and are accentuated by the synclinal elements of the crumples. (See also fig. 20.)

It is these overdeepened involutions in the old troughs that have localized the ore deposits of this area. The more easterly one crosses the East fissure at the very nose of the trough inclosed between this fault and the South fault, forming the Tintic Standard "pothole." The more westerly involution intersects the East fissure at the North Lily mine, in the northwest corner of the same trough. On its extension southward it passes just west of the present lowest ore in the Eureka Standard mine.

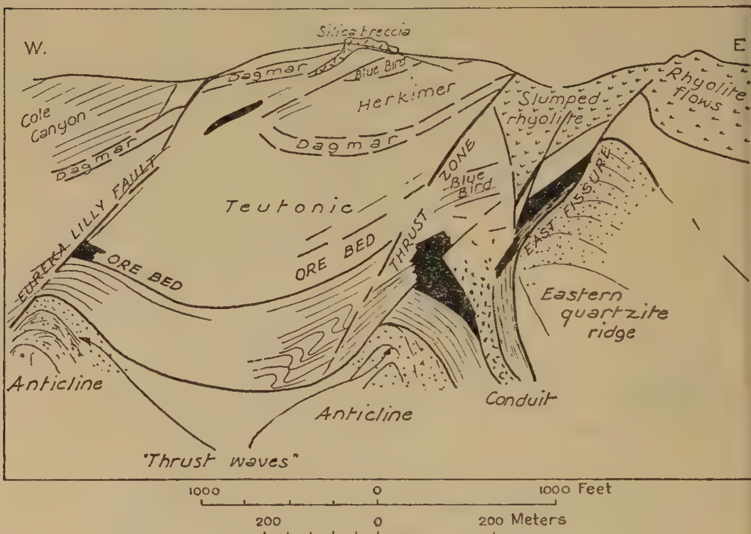

FIGURE 20.—East-west section of Tintic Standard trough

Associated with each intersection are northeast fissures, later than the crumples, which have guided successively monzonite, porphyry, pebble dikes, and ore mineralization. These fissures have slight displacement and are believed to represent a final adjustment following the thrust and crumple stage of deformation.

The ore foci developed at these critical intersections run up through the normal sequence of vein roots, pipe, expanding funnel, and finger-tip extensions. They do not enter the rhyolite blanket as ore, but their alteration halo penetrates this blanket, largely guided by the northeast fissures. If viewed from the air, therefore, the rhyolite over East Tintic would show a chain of large bleached patches. Three of these patches would prove to overlie the North Lily, Tintic Standard, and Eureka Standard ore bodies; the others would overlie areas yet to be developed. The pattern of this surface alteration is shown on Figure 21.

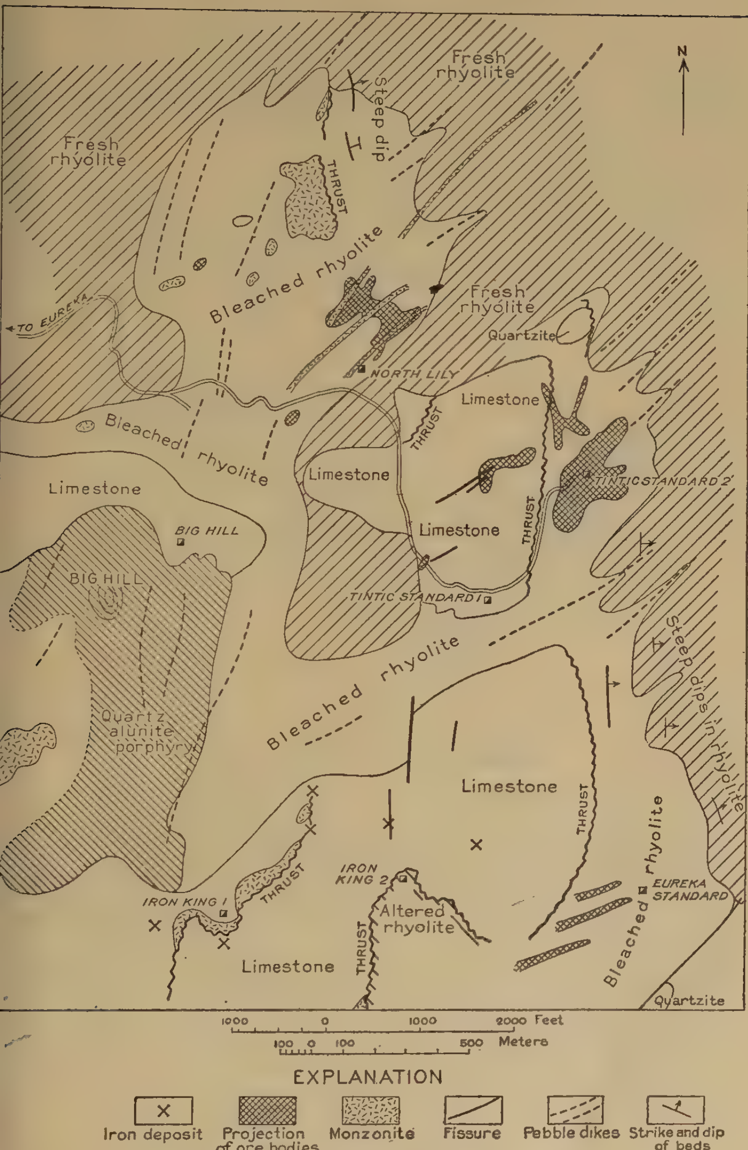

FIGURE 21.—Surface alteration, East Tintic

The nature of this alteration ranges from mere chloritization at the outer margin to intense sericitization and pyritization farther in. Tiny veinlets of quartz are abundant in the strongly altered areas, and a few of these show a little pyrite and barite. Around the Big Hill center the porphyry is drenched with silica and the feldspars are completely alunitized. The only dark mineral here is magnetite.

Immediately above each ore deposit there is an abnormal depression in the land surface, a feature due to the shrinkage of the rock below under the combined effects of mineralization and oxidation. Postoxidation slumping is found on a large scale in the limestone immediately above the ore.

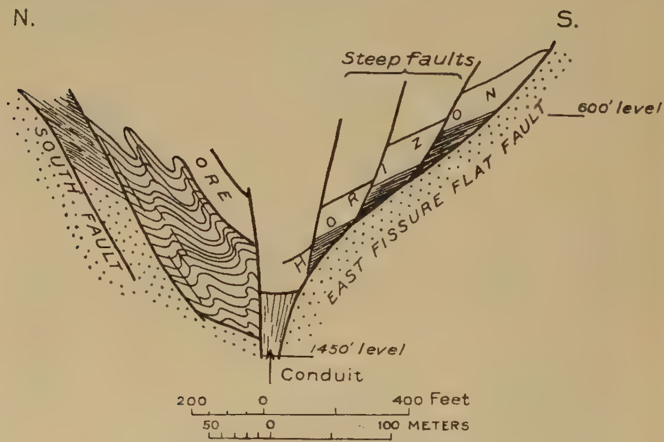

FIGURE 22.—North-south section of Tintic Standard trough

The thin-bedded and incompetent Ophir formation rests on the basal quartzite and is overlain by the massive Teutonic limestone. The Ophir, about 400 feet (122 meters) thick, is composed of three shale members separated by two limestones, the lower of which carries the ore.

This series displayed extreme plasticity under the stress of folding and faulting. In general the shale members were pulled out thin along the northern edge of the trough but overthickened against the South fault. (See fig. 22.)

COMPOSITE PLAN OF ORE BODIES, TINTIC STANDARD MINE

Numbers indicate levels.

The beveled edge of the bed of favorable limestone, resting upon the basal quartzite of the East fissure footwall, is one of the principal ore foci of the mine. The upper limit of ore is reached in the highest point of this overlap of the ore bed. From this edge back to the final steep hanging-wall branch of the East fissure the ore bed is, in most of the mine area, thoroughly replaced by ore. The northeastern ore bodies of the upper levels are found in this structural segment.

The relationship of these ore bodies to the deeper ones is well exhibited on Plate 13, which shows at a glance the entire range of ore deposition from the central pipe or conduit on the 1,450 level into the expanded funnel of encircling Ophir limestone on the 1,350, 1,200, and 1,100 levels and on into the various extensions upward. The northeastern and eastern extensions occupy the ore bed on the shelf between the steep and flat branches of the East fissure. The northern extension follows a thrust line which coincides approximately with the western edge of the sharp synclinal crumple. The ore bodies to the northwest, formerly regarded as disconnected, have recently been tied in to the old system by the discovery of continuous intervening ore. They extend along the intersection of the ore bed with a southerly branch of the East fissure and are largest where this branch, by pulling apart the shale, has left the Ophir limestone against basal quartzite.

All the phases of Tintic mineralization are found in the Tintic Standard mine, although the closest porphyry dike is 1,000 feet (305 meters) to the southwest. The entire pothole area has been dolomitized, so that Ophir limestone, normally pure lime, contains 35 per cent or more of magnesia. Great areas have also been silicified, particularly to the west on lower levels, where a gray fine silica speckled with kaolin has completely replaced portions of the lower Ophir shale. Pebble dikes traverse the heart of the mine, although not so numerous as in the neighboring North Lily.

The products of the first stage of ore mineralization, with its barite, pyrite, enargite, and tetrahedrite, are found in the fissure roots of all the ore bodies and also in large volume in the southeast corner of the pothole. Marcasite is in places the final primary mineral of this stage. The later stage of mineralization deposited quartz with galena and pyrite. This makes up the great volume of the ore deposits, which range from very siliceous silver ores to base lead-silver ores or to pyritic silver ore. In many ore beds different layers were differently replaced, a bed of siliceous ore immediately overlying a lead bed, or vice versa.

Oxidation is almost complete down to the 900 level and is partial to the 1,250 level. The oxidized ores of the upper levels contain locally silver jarosite, bunches of which have yielded carload shipments worth $60,000 a car. Normally the oxidized ore is about twice as rich in silver as the sulphide, with no difference in other metals.

SUMMARY OF TRIP

The Union Pacific Railroad station at Eureka affords a convenient base for the inspection of the steep western limb of the Tintic syncline and of the crumpled structure developed in the southwestern wedge block. These can be seen on the surface in the area southwest of the town. In this same area are the outcrops of the Eureka Hill ore bodies.

The town of Eureka overlies the Chief Consolidated ore focus. Little can be seen of this on the surface, however—merely the effects of the alteration and mineralization which have leaked up along the faults that edge the rhyolite basin here.

The road to Dividend, where the Tintic Standard mine is situated, is almost entirely over the rhyolite, but it affords at first a good general view of Godiva Mountain on the south and in its last mile a view of the entire East Tintic area. The alteration patches and topographic depressions over the North Lily and Tintic Standard ore bodies are close to the road, and within a few steps pebble dikes and monzonite stocks can be examined.

An underground trip in the Tintic Standard mine affords an opportunity to see the conduit breccia of the lower levels, the encircling sulphide ore bodies, the high-grade oxidized ore of the northeast shelf, and the principal structural elements, such as the East fissure, South fault, and northeast fissures.

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EXCURSION 8.—SALT LAKE CITY TO MONTPELIER, IDAHO

By G. R. MANSFIELD

THE WESTERN PHOSPHATE FIELD

General features.—The States of Idaho, Utah, Wyoming, and Montana and parts of Alberta and British Columbia contain extensive deposits of phosphate rock of Permian age. The area occupied by these deposits is known in the United States as the western or Rocky Mountain phosphate field and is one of the three great phosphate fields of the world. These phosphate deposits are estimated to contain a reserve supply of rock phosphate aggregating more than 6,000,000,000 metric tons. The reserves in Idaho, which constitute about five-sixths of those mentioned for the western field, range from 60 to more than 70 per cent in tricalcium phosphate content. The field, however, is more remote from existing markets than the much smaller phosphate fields of Florida and Tennessee, which yield the bulk of present production in this country. The annual production in the western field has up to the present time amounted to less than 2 per cent of the total for the country. In 1930 the quantity mined here was 71,473 long tons, as compared with 3,951,353 long tons for the country as a whole.

The largest individual producer in the western field is the Anaconda Copper Mining Co., whose mine is located at Conda, Idaho, about 7 miles (11 kilometers) northeast of Soda Springs. The rock from this mine is largely shipped to Anaconda, Montana, where it is treated with sulphuric acid derived from the company's smelter to produce "Anaconda treble superphosphate" averaging approximately 45 per cent of available phosphoric acid.

Conda.—The phosphate at Conda occurs in the lower or phosphate shale member of the Phosphoria formation, of Permian age, which in a section measured in Trail Canyon, about 3 miles (4.8 kilometers) to the southeast, is about 450 feet (137 meters) thick. Of this thickness about 100 feet (30 meters) is included in the shale member and the remaining 350 feet (107 meters) in the upper or Rex chert member. The main phosphate bed, dark brown or black and oolitic, is 7 to 10 feet (2 to 3 meters) thick, averages 72 per cent or more of tricalcium phosphate, and lies within a few feet of the base of the section. The underlying Wells formation, of Pennsylvanian age, is about 2,400 feet (732 meters) thick and consists principally of gray limestone in its upper and lower parts but contains perhaps

1,000 feet (305 meters) of varicolored sandy and calcareous beds in the middle. The overlying Lower Triassic formations, the Woodside and Thaynes, comprise beds of impure limestone and calcareous sandstone and shale, generally light colored, olive-drab, or brown and altogether about 3,000 feet (914 meters) thick. The Phosphoria is unconformable with the Wells below and the Woodside above. The general stratigraphic and structural relations are shown in Plate 14.

Conda is a town built and operated by the Anaconda Copper Mining Co. in connection with its phosphate mine.

On the company's property there are parts of two large anticlines with northwesterly strike, together with some subordinate folds, which furnish three principal outcropping bands of the phosphate beds. Two of these bands lie along the east and west limbs of the western or Emma anticline and converge at a point about a quarter of a mile (0.4 kilometer) east of the town. The third band lies about 1¼ miles (2 kilometers) farther northeast and is part of the east limb of the broken eastern anticline. Production thus far has been derived principally from the band on the east limb of the Emma anticline, where the beds are less disturbed and broken than in the west limb.

The mines at Conda are opened through two adits, which are about half a mile (0.8 kilometer) apart at the portals and about the same distance underground. Adit No. 1, whose portal is at an altitude of 6,256 feet (1,907 meters), reaches the eastern phosphate band of the Emma anticline about 2,300 feet (701 meters) from the entrance. In 1931 it was being extended northeastward to intercept the third band at a distance of about 6,500 feet (1,981 meters). In the third band backs of 300 to 1,300 feet (91 to 396 meters) will be obtained. Adit No. 2 enters the western phosphate band of the Emma anticline 750 feet (229 meters) from the portal. A fine exposure of the Rex chert, the upper member of the Phosphoria formation, is displayed at the entrance of adit No. 1, where the beds dip strongly westward.

Raises 100 feet (30 meters) apart have been run from the adit level to the top of the ore, and intermediate small drifts driven from the raises at 100-foot intervals. There are in some places as many as six of these intermediate levels. The phosphate in the Emma anticline is thoroughly blocked out and partly mined. The ore is soft and friable but moist enough to prevent the formation of dust. There is practically no water in these workings, but in the extension adit considerable flows of water have been encountered, which now escape through adit No. 1.

Crushing and drying constitute the only treatment given to the rock at Conda. From the mines the rock is hauled to the

mill-feed bin, which has a capacity of about 350 tons. Thence movement of the ore through crusher, screens, rolls, and dryer is continuous to railroad storage bins, the larger of which has a capacity of 3,000 tons and unloads directly into open cars. The other bin, whose capacity is 1,000 tons, is arranged to load box cars by an electrically operated loader.

BANNOCK OVERTHRUST

One of the outstanding structural features of southeastern Idaho and indeed of the entire northern Rocky Mountain region is the Bannock overthrust. This great fault, described in 1912 (111, 112) [19] and elaborated in later publications (109, 110), has been traced from northeastern Utah northward and northwestward for about 270 miles (435 kilometers) into Idaho as far as the southeast border of the Snake River Plain. (See pl. 15.) On the Continental Divide, however, some 80 miles (129 kilometers) northwest of that place, a fault of similar habit has been recognized which may prove to be its continuation in that direction. Other overthrusts still farther northwest are known, and it seems fairly certain that they are closely related.

The rocks of the upper fault block of the Bannock overthrust are strongly folded, with the development of fan folds in some places, and most of the folds are inclined eastward to a greater or less extent. These facts indicate that the general folding of the region was well advanced before overthrusting began.

The epoch of Bannock overthrusting falls between Lower Cretaceous and early Eocene time and is assigned to the so-called Laramide revolution. Other overthrusts in the northern Rocky Mountains occurred at about the same time but were not synchronous with the Bannock. It is believed that the overthrusting continued intermittently over an extended epoch and that it began earlier in the more westerly areas and progressed gradually eastward so that the more easterly thrusts are in general younger. The Bannock overthrust perhaps occupies an intermediate position between the older and younger thrusts.

The margin of the overthrust block is very irregular and transgresses many folds in the underlying block. The structural overlap produced by the fault is approximately 35 miles (56 kilometers). (See pl. 15.) Doubtless the upper block has been eroded back to some extent so that the original structural overlap may have been wider. The plane of the Bannock overthrust has been folded into broad anticlines and synclines. In some of the anticlines the upper block has been eroded sufficiently to produce

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[19] Numbers in parentheses refer to bibliography, pp. 145–146.

windows, through which formations of the underlying block may be seen. These windows lie from 9 to 25 miles (14 to 40 kilometers) back from the trace of the overthrust and bear witness to the general flatness and shallowness of the thrust plane. At some places the margin of the upper fault block is bordered by a single fault; elsewhere it is imbricated with five or six branch faults separating a corresponding number of rock slices. Plate 16 shows the general outline of the Bannock overthrust and associated thrusts and indicates the position of the windows.

The largest window is nearly 25 miles (40 kilometers) long and has a maximum width of about 5 miles (8 kilometers). Much of its area is concealed by Tertiary and Quaternary deposits and by basalt, but Threemile Hill, on the west side of the road between Conda and Soda Springs, and the Triassic hills northwest and southwest of Georgetown, together with some other Triassic areas, are parts of the lower fault block exposed through this window. On Threemile Hill there are large blocks or boulders of Ordovician quartzite and limestone that overlie Lower Triassic (Thaynes) beds and are interpreted as erosion remnants of the upper fault block. (See pls. 15, 16.)

One of the best places to see the Bannock overthrust is the Georgetown Canyon area. The left fork of the creek occupies a valley carved in an anticline in the plane of the Bannock overthrust. The upper block, composed of Carboniferous limestones, has been eroded away, and in the underlying block Jurassic beds are exposed. This exposure is essentially a window in the upper fault block, but it is not fully inclosed on the south.

The right fork of Georgetown Canyon, which contains the main stream, occupies a bifurcated syncline in the upper fault block and for much of its course lies in beds of Lower Triassic age, but in its lower part it crosses Carboniferous limestones and then directly emerges on Jurassic beds exposed in the southern extension of the window opened by the left fork. Before joining the left fork, however, it again crosses Carboniferous beds, which a short distance beyond are covered by Tertiary strata.

Between the two forks of the canyon the ridges of Jurassic rocks belonging to the lower block are in part overspread by ledges of lower Carboniferous rock comprising part of the upper block, which extend down the interstream ridges like great fingers, whereas the intervening gullies are carved in Jurassic beds. (See pl. 16.)

The crossing of the western trace of the Bannock overthrust in Georgetown Canyon is not particularly noteworthy, though Carboniferous ledges may be seen on the north side of the canyon, immediately west of the Jurassic beds. The eastern trace

at the crossing of the canyon, however, is spectacular, for here the Carboniferous ledges form an impressive gateway. The fault crosses the canyon southeastward in a fairly straight line and at this point therefore has a steep dip. Farther southeast the dip becomes gentler, and the fault trace in crossing the Preuss Range turns back northeastward, thereby delimiting the south end of a broad syncline in the fault plane that pitches northward. (See pl. 17.)

At the place where the east fault trace crosses Georgetown Canyon a small side valley, known as Church Hollow, enters from the north. This valley follows the fault line northwestward for about a mile (1.6 kilometers) and affords a good view of the general relations. Toward the head of Church Hollow the fault trace may be seen to turn back westward and climb the ridge on which the fault plane lies relatively flat. Southeastward the fault between the Mississippian and the Jurassic lies on a relatively smooth slope, and its position is not readily distinguishable from a distance.

Between Georgetown and Montpelier the trace of the Bannock overthrust is largely concealed by Tertiary and Quaternary sediments, but southeast of Bennington massive ledges of Carboniferous limestone can be seen lapping up on the mountain side, where they form a crescentic mass about 4 miles (6.4 kilometers) long, north and south, and 2 miles (3.2 kilometers) wide, which on the east overrides beds of Lower Triassic age. At the mouth of Montpelier Canyon, about a mile (1.6 kilometers) from the center of the town of Montpelier, beds of upper Mississippian age overlie Lower Triassic strata, which are here much shattered.

Except for the Carboniferous ledges that extend about 2 miles (3.2 kilometers) south of Montpelier along the foothills, there is no evidence of the further continuation of the fault trace southward on the east side of the Bear Lake Valley, and it is believed to loop westward under alluvial and Tertiary cover to the west side, where it appears again along the foothills of the Bear River Range west of Ovid. For a part of this distance the Phosphoria formation in the lower block is exposed just east of the fault trace, and phosphate has been mined in some of the canyons that cross the fault zone. Toward the south the fault zone becomes imbricated, and west of St. Charles as many as six rock slices, each containing parts of broken folds, have been recognized.

Because of the intense folding experienced by the rocks of both the upper and the lower blocks no accurate statement of the amount of vertical displacement can be made. Where the fault branches the stratigraphic throw is distrubuted among the dif-

ferent members, in some of which it may not exceed 1,000 feet (305 meters). The cumulative stratigraphic throw of all branches in a given area may amount to 15,000 to 20,000 feet (4,600 to 6,100 meters).

LOWER PALEOZOIC STRATIGRAPHY

The stratigraphy of southeastern Idaho presents a long and fairly continuous record, though many gaps of longer or shorter duration are recognized. All the great systems and most of the series from lower Paleozoic to Recent are represented. The total thickness of the sedimentary rocks present in the region is greater than 46,000 feet or 8.7 miles (14 kilometers).

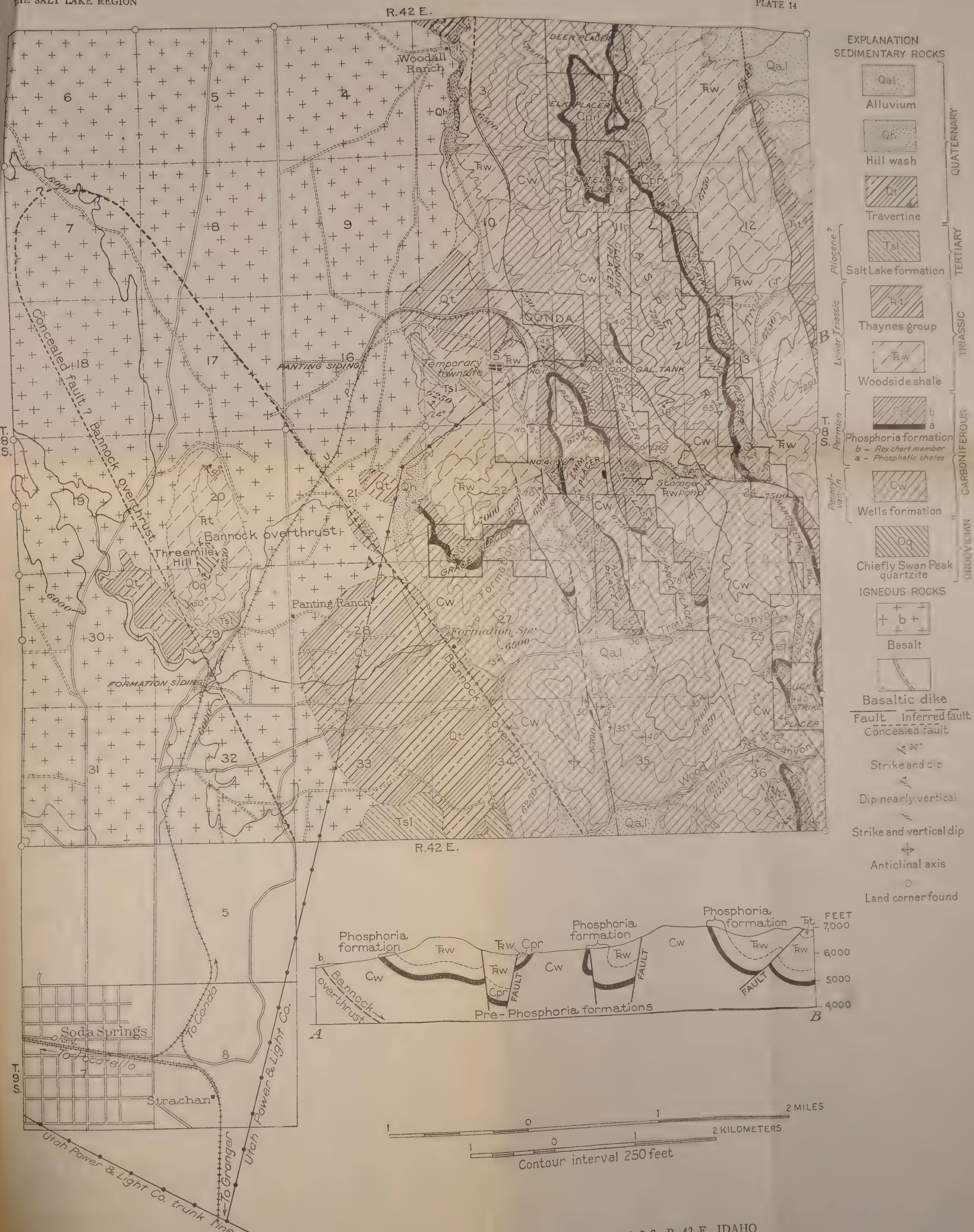
The lower Paleozoic systems are well developed in the Bear River Range, which occupies the western part of the Montpelier quadrangle, Idaho, and adjacent areas, and in the Wasatch Range, part of which lies in the Logan quadrangle, Utah. The Cambrian rocks have been subdivided by Walcott (114, 115) into seven formations and have an aggregate thickness in southeastern Idaho of about 7,000 feet (2,100 meters). Walcott's section of the Cambrian on Blacksmith Fork in the Logan quadrangle, Utah, has become the classic section for this part of the Rocky Mountains. Similarly Richardson's section of the Ordovician and Silurian in the Randolph quadrangle, Utah (113), has become standard for the same general region.

BLACKSMITH FORK SECTION

Walcott (115) describes the Blacksmith Fork section as "located in Blacksmith Fork Canyon, on the east side of Cache Valley, in the Wasatch Mountains, between Ute and Logan Peaks, about 10 miles [16 kilometers] east of Hyrum, in northern Utah." The general topography of the canyon and the neighboring uplands occupied by the Cambrian beds is well shown on the topographic map of the Logan quadrangle. Walcott's section, with thicknesses in meters added, is as follows:

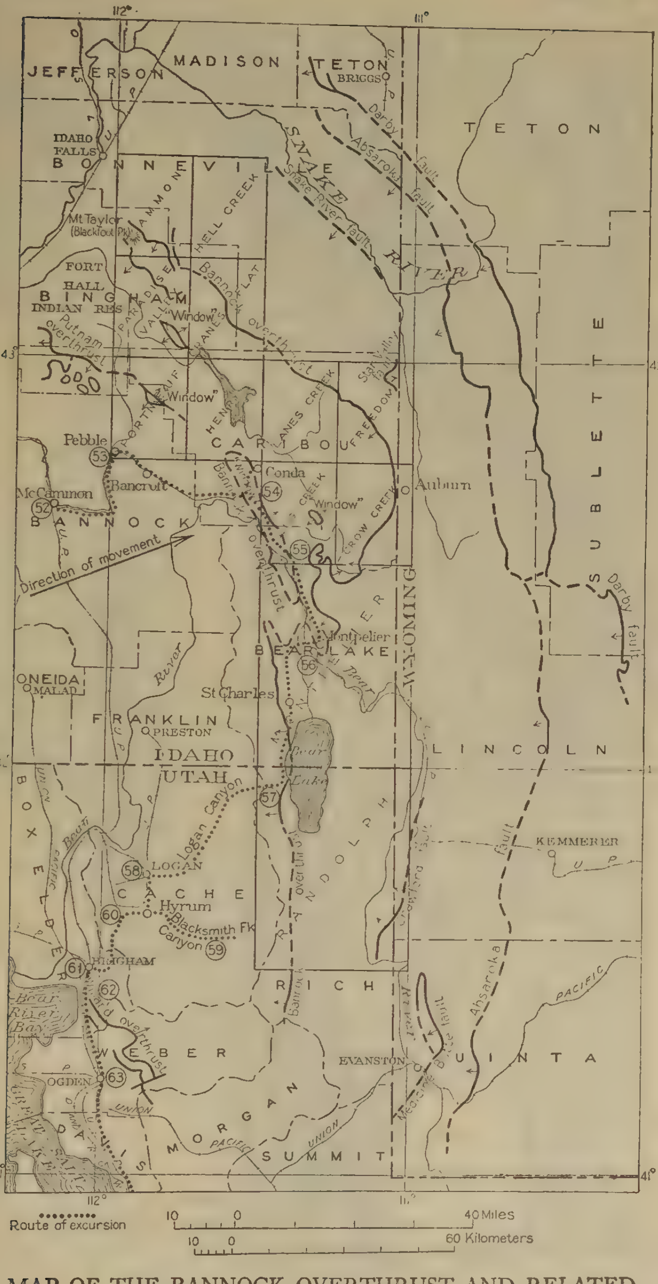
ORDOVICIAN

Dark, bluish-black, and gray limestone. In the basal bed immediately above the Cambrian a fine fauna occurs. The limestone is of the same character as that of the Upper Cambrian for 190 feet [58 meters] below, and, except for the change in the fauna, there is no break in the section. One of the characters common to the Cambrian and the superjacent Ordovician is the presence in most layers of flattened concretionary nodules and stringers from a minute size up to 6 or 8 centimeters or more in diameter; the large ones rarely exceed 3 to 10 millimeters in thickness. *Eoorthis desmopleura*, *Syntrophia nundina*, *Orthoceras*, *Endoceras*, fragments of trilobites.



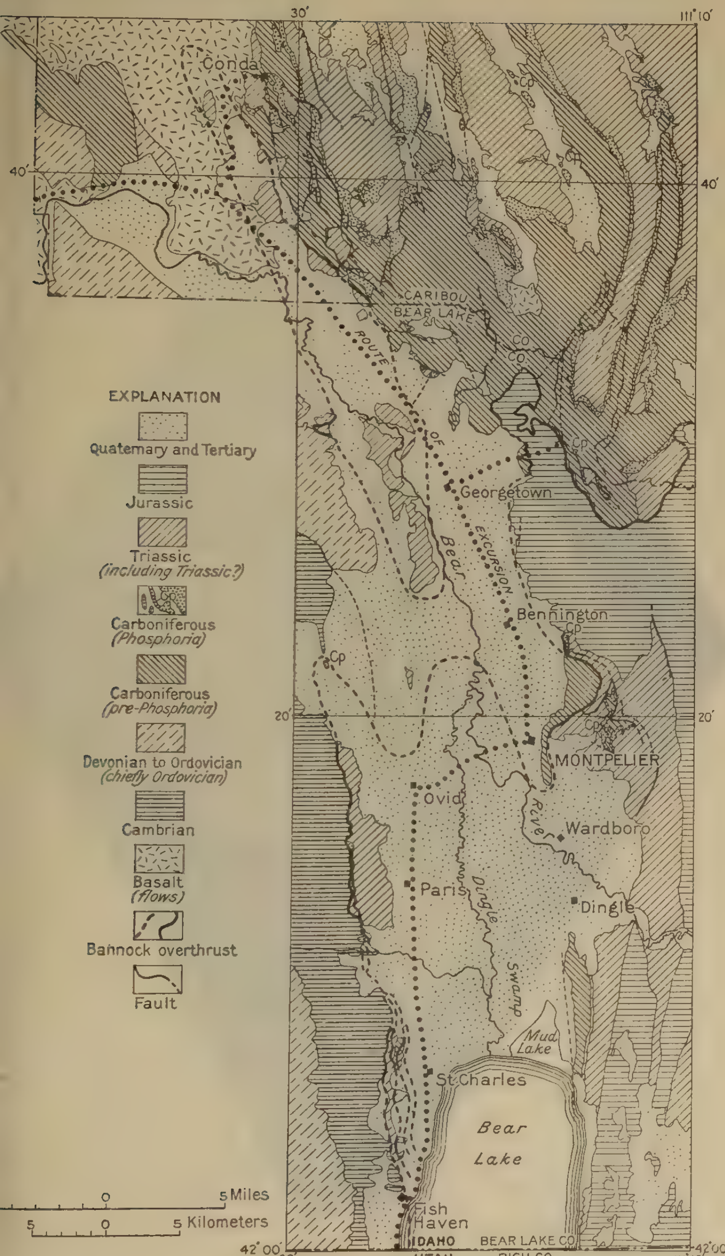
GEOLOGIC MAP AND STRUCTURE SECTION OF THE CONDA PHOSPHATE AREA, T. 8 S., R. 42 E., IDAHO

From U. S. Geol. Survey Prof. Paper 152, pl. 44, 1927.



MAP OF THE BANNOCK OVERTHRUST AND RELATED THRUSTS

Short arrows show dip of fault planes. From U. S. Geol. Survey Bull. 803, fig. 2, 1929.



MAP OF THE BANNOCK OVERTHRUST REGION FROM CONDA TO BEAR LAKE

From U. S. Geol. Survey Prof. Paper 152, pl. 1, 1927.

STEREOGRAM OF PART OF REGION TRAVERSED BY BANNOCK OVERTHRUST

Tps. 9–11 S., Rs. 43–45 E. From U. S. Geol. Survey Bull. 577, pl. 3, 1914.

UPPER CAMBRIAN

	Feet	Meters
St. Charles limestone:		
1. Dark, bluish-gray, and gray limestone	190	58
25 feet [8 meters] below the top: *Lingulella manticula, Eoorthis desmopleura, Syntrophia nundina, Dicellocephalus.* 105 to 125 feet [32 to 38 meters] below the top: *Schizambon typicalis, Eoorthis desmopleura, Eoorthis newberryi, Syntrophia nundina, Solenopleura, Menocephalus, Illaenurus.* 20 to 30 feet [6 to 9 meters] above the base: *Lingulella (Lingulepis) acuminata, Eoorthis desmopleura, Eoorthis newberryi, Agnostus, Solenopleura, Menocephalus, Asaphus?*		
2*a*. Massive dark-gray arenaceous limestone	195	59
2*b*. Massive gray arenaceous limestone with a few irregular cherty layers	100	30
2*c*. Gray siliceous and arenaceous limestone	85	26
Obolus (Westonia) iphis, Lingulella desiderata.		
2*d*. Massive arenaceous limestone	397	121
3. Bedded bluish-gray fossiliferous limestone	94	29
Upper part: *Acrotreta* sp., *Anomocare.* Near base: *Obolus* sp. undet., *Lingulella manticula, Billingsella coloradoensis, Agnostus, Ptychoparia, Anomocare.* A mixture of the faunas at the base and at the top: *Obolus discoideus, Obolus?* sp. undet., *Lingulella manticula, Billingsella coloradoensis, Huenella lesleyi, Hyolithes, Cyrtolites, Agnostus, Ptychoparia, Anomocare.*		
4. Sandstone, light-gray to brown, shaly and thin-bedded near the base	166	51
In upper 20 feet: *Obolus discoideus, Obolus (Fordinia) bellulus, Acrotreta idahoensis alta, Billingsella coloradoensis.* Near the base: *Lingulella (Lingulepis) acuminata.*		
Total Upper Cambrian (St. Charles limestone)	1,227	374

MIDDLE CAMBRIAN

	Feet	Meters
Nounan limestone, light or dark gray beds, arenaceous throughout and cherty near base	1,041	317

A few traces of fossils occur in the lower 28 feet and large annelid borings occur in many of the arenaceous limestones. In the dark rock the irregular borings are filled with lighter-colored rock, and in the light-gray rock by darker rock.

	Feet	Meters
Bloomington formation:		
1*a*. Thin-bedded bluish-gray limestone	22	7
Protospongia (spicules), *Obolus mcconnelli pelias, Obolus (Westonia) wasatchensis, Lingulella desiderata, Hyolithes, Agnostus, Ptychoparia.*		
1*b*. Greenish argillaceous shale	12	4
1*c*. Gray coarse-grained limestone	13	4
Hyolithes, Ptychoparia.		
1*d*. Greenish argillaceous and sandy shale	147	45
Hyolithes (fragments), *Agnostus, Ptychoparia.*		
1*e*. Gray coarse-grained limestone	4	1
Micromitra sculptilis, Hyolithes (abundant), *Ptychoparia, Agraulos.*		
1*f*. Greenish argillaceous and sandy shale	22	7

	Feet	Meters
Bloomington formation—Continued.		
2*a*. Bluish-gray limestones	380	116
Fragments of fossils.		
2*b*. Massive gray limestone	132	40
Ptychoparia, *Agraulos* (same as in 1*e*).		
2*c*. Bluish-gray limestone similar to 2*a*	290	88
Hyolithes, *Agraulos*.		
2*d*. Greenish argillaceous shale	39	12
Obolus (*Westonia*) *wasatchensis*, *Agraulos*, *Ptychoparia*.		
2*e*. Bluish-gray thin-bedded limestone	182	55
2*f*. Arenaceous steel-gray limestone	22	7
2*g*. Bluish-gray limestone	55	16
Micromitra sculptilis, *Ptychoparia*, *Dorypyge*.		
Total of Bloomington formation	1,320	402
Blacksmith limestone:		
1*a*. Dark lead-gray arenaceous limestone	195	59
1*b*. Arenaceous steel-gray limestone, in the lower portion passing into a dove-gray compact limestone	375	114
Fragments of a small trilobite (*Ptychoparia*?), annelid borings.		
Total of Blacksmith limestone	570	173
Ute limestone:		
1*a*. Bluish-gray compact thin-bedded limestone, with large irregular annelid borings in the upper part	290	88
In upper part: *Micromitra* (*Paterina*) *labradorica utahensis*, *Billingsella* sp. undet., *Hyolithes*, *Agraulos*, *Ptychoparia subcoronata*, *Dorypyge? quadriceps*.		
1*b*. Gray arenaceous limestone in thin layers, often oolitic, and with interformational conglomerate and flattened concretions	135	41
In the upper 5 feet [1.5 meters], *Scenella*, *Ptychoparia subcoronata*, *Dorypyge? quadriceps*. In layers 70 to 80 feet [21 to 24 meters] below the top: *Micromitra* (*Paterina*) *labradorica utahensis*, *Obolus mcconnelli*, *Acrotreta* cf. *A. ophirensis*, *Acrotreta* sp. undet., *Billingsella coloradoensis*, *Otusia utahensis*, *Eoorthis zeno*, *Syntrophia cambria*, *Hyolithes*, *Scenella*, *Zacanthoides*, *Ptychoparia subcoronata*, *Dorypyge? quadriceps*.		
1*c*. Gray limestone. A few thin layers of interformational conglomerate and some shaly limestone	58	18
2*a*. Gray fine-grained calcareous and argillaceous shaly beds	38	12
Micromitra (*Paterina*) *labradorica utahensis*, *Obolus* (*Westonia*) *ella*, *Acrothele turneri?*, *Isoxys* cf. *I. argentea*, *Ptychoparia*.		
2*b*. Bluish-gray to blue-black fine-grained thin-bedded limestone	57	17
Obolus? Ptychoparia.		
2*c*. Greenish argillaceous and calcareous shale, weathering buff	51	16
2*d*. Thin-bedded grayish-blue limestone	36	11

	Feet	Meters
Ute limestone—Continued.		
2*e*. Gray oolitic limestone	24	7
Micromitra (*Paterina*) *stuarti*, *Micromitra* (*Paterina*) *superba*, *Hyolithes*, *Ptychoparia*, *Dorypyge* (fragment).		
2*f*. Greenish argillaceous and sandy shale	18	5
Micromitra (*Paterina*) *superba*, *Obolus mcconnelli*, *Ptychoparia* sp. undet.		
2*g*. Bluish-gray thin-bedded limestone	22	7
Micromitra (*Paterina*) *superba*, *Hyolithes*, *Ptychoparia* (small heads).		
2*h*. Spence shale member (Greenish argillaceous and sandy shale)	30	9
Micromitra (*Iphidella*) *pannula*, *Obolus* (*Westonia*) *ella*, *Lingulella desiderata*, *Hyolithes*, *Orthotheca major*, *Leperditia*, *Ptychoparia*, *Bathyuriscus productus*.		
Total of Ute limestone	759	231
Langston limestone:		
1*a*. Massive, bluish-gray limestone passing downward into gray arenaceous limestone	64	20
Obolus (*Westonia*) *ella*, *Zacanthoides* sp., *Bathyuriscus productus*, *Neolenus*?.		
1*b*. Massive bluish-gray limestone	44	13
Ptychoparia, *Bathyuriscus productus*.		
2. Massive-bedded dark arenaceous limestone, passing at about 150 feet [46 meters] down into a calcareous sandstone and then a gray sandstone	390	119
Total of Langston limestone	498	152

MIDDLE AND LOWER CAMBRIAN

	Feet	Meters
Brigham quartzite:		
1*a*. Gray quartzitic sandstone, weathering reddish brown	28	9
1*b*. Greenish hard sandy shale	4	1
Annelid trails, trilobite tracks.		
1*c*. Same as 1*a* (estimated)	1,200	366
Total of Brigham quartzite	1,232	376
Total Middle Cambrian	5,420+	1,652+
Total Cambrian	6,647+	2,026+

Walcott's description does not suggest that any of the limestone formations are dolomitic. The Langston limestone, however, is strongly dolomitic and rather coarsely crystalline and has a steely light-gray fracture when freshly broken. This lithology is repeated in some of the higher formations, notably portions of the Blacksmith, Bloomington, Nounan, and St. Charles, all of which are in part dolomitic.

PALEOZOIC SECTION IN NORTHERN UTAH

Richardson (113) found "one of the most complete Paleozoic sections known in the entire Cordilleran region exposed in the vicinity of Bear Lake, northern Utah. This section embraces more than 14,000 feet [4,300 meters] of strata and includes seven Cambrian, three Ordovician, one Silurian, two Devonian, and four Carboniferous formations." He considered it desirable in the preparation of his geologic map of the Randolph quadrangle to differentiate the Hodges shale member at the base of Walcott's Bloomington formation (Middle Cambrian) and the Worm Creek quartzite member at the base of Walcott's St. Charles limestone (Upper Cambrian).

Richardson's entire Paleozoic section with very slight modification as to ages is given below for reference, as it is generally applicable to Blacksmith Fork Canyon, which is one of the objectives of the excursion. Attention is chiefly directed, however, to the Silurian and Ordovician formations, which are crossed in descending order as the Cambrian section is approached in the canyon.

Paleozoic formations in northern Utah

System	Series or fauna	Formation	Approximate thickness		General character
			Feet	Meters	
Carboniferous.	Permian	Phosphoria formation	400	122	Chert and siliceous limestone overlying shale, thin limestone, and oolitic phosphate rock.
	Pennsylvanian	Wells formation	Less than 300–600	91–183	Massive gray quartzite overlain and underlain by thinner-bedded quartzite and limestone.
	Mississippian	Brazer limestone	800–1,400	244–427	Massive to thin-bedded light-gray siliceous limestone and sandstone.
		Madison limestone	600–1,600	183–488	Medium to thin bedded dark limestone rich in fossils.
Devonian.	Upper	Threeforks limestone	200	61	Soft reddish rocks poorly exposed in Randolph quadrangle.
	Middle	Jefferson dolomite	1,200	366	Massive fine-grained dark dolomite; weathers a characteristic brown tint.
Silurian.		Laketown dolomite	1,000	305	Massive light-gray dolomite.
Ordovician.	Richmond fauna	Fish Haven dolomite	500	152	Medium-bedded bluish dolomite.
	Chazy (?) fauna	Swan Peak quartzite	500	152	Fine-textured gray quartzite.
	Beekmantown fauna	Garden City limestone	1,000	305	Thick and thin bedded gray limestone.

Paleozoic formations in northern Utah—Continued

System	Series or fauna	Formation	Approximate thickness		General character
			Feet	Meters	
Cambrian.	Upper	St. Charles limestone, with Worm Creek quartzite member.	Less than 500 to 1,300	152–396	Massive gray limestone with 300 feet of massive gray quartzite at the base.
		Nounan limestone	950	290	Massive to medium-bedded gray limestone.
	Middle	Bloomington formation, with Hodges shale member.	1,250	381	Thin-bedded limestone and shale.
		Blacksmith limestone	750	229	Massive fine-grained gray to bluish limestone.
		Ute limestone, with Spence shale member.	480–585	146–178	Thin limestone, interbedded with shale.
		Langston limestone	375	114	Massive crystalline blue to gray limestone.
	Middle and Lower	Brigham quartzite	1,600+	488+	Massive fine-grained gray quartzite locally conglomerate.
		Base not exposed.			

Silurian.—The Laketown dolomite is a massive light-gray dolomite, containing bands of calcareous sandstone, having a thickness of approximately 1,000 feet (305 meters). *Pentamerus* cf. *P. oblongus* Sowerby occurs locally. Specific identification is impossible, but this fossil clearly points to the Silurian age of the containing beds. Some poorly preserved corals identified provisionally as *Halysites catenulatus?* Linnaeus, *Favosites* sp., and *Cyathophyllum?* sp. were found in the lower part of the dolomite in Laketown Canyon. Kirk assigns the fossils from the Laketown to the Niagaran epoch of the Silurian.

Ordovician.—The Ordovician beds adjacent to the Idaho-Utah State boundary are represented by 2,000 feet (610 meters) of strata, which at some places are almost continuously exposed. They are separated into three formations—the Garden City limestone, containing a Beekmantown fauna; the Swan Peak quartzite, containing a Chazy (?) fauna; and the Fish Haven dolomite, characterized by a Richmond fauna. There is evidence of erosional unconformity at the base of the lowermost and uppermost Ordovician formations.

An extensive fauna has been collected from the Garden City limestone in the Montpelier and Randolph quadrangles, from which the following list has been selected as characteristic by Edwin Kirk:

Dalmanella pogonipensis Hall and Whitfield.
Dalmanella hamburgensis Walcott.
Syntrophia near S. calcifera Billings.
Strophomena? minor Walcott.
Polygrata rotuliformis Meek.
Polygrata trohiscus Meek.
Raphistoma? acutum Hall and Whitfield.
Maclurea subannulata Walcott.
Eccyliopterus sp.
Lophospira sp.
Hormotoma sp.
Bucanella nana Meek.
Endoceras sp.
Asaphus? near A. curiosus Billings.
Bathyurus sp.
Receptaculites sp.

The fauna of the Garden City limestone is of Beekmantown age and corresponds to the main mass of the Pogonip limestone of the Eureka district, Nevada.

The Swan Peak quartzite is a fine-textured massive to thin-bedded white to gray quartzite about 500 feet (152 meters) thick which lies, apparently conformably, on the Garden City limestone. The following fossils were obtained from this quartzite in the Randolph quadrangle: *Orthis* n. sp., near *O. tricenaria* Conrad, *Eccyliomphalus* sp., *Endoceras* sp., *Ampyx*?,

Symphyurus? goldfussi Walcott, *Bathyurus congeneris* Walcott, *Leperditia* sp., *Leperditella* sp. This fauna is referred tentatively to the Chazy by Ulrich and Kirk.

Immediately overlying the Swan Peak quartzite is the Fish Haven dolomite, a fine-textured medium-bedded dark-gray to blue-black, locally cherty formation about 500 feet (152 meters) thick, containing *Calapoecia* cf. *C. canadensis* Billings, *Streptelasma* sp., *Halysites catenulatus* var. *gracilis* Hall, *Rhynchotrema* cf. *R. capax* Conrad, and *Columnaria thomii* Hall. These fossils represent a widespread western Richmond fauna.

ITINERARY

McCAMMON TO MONTPELIER

[52][20] McCammon, the junction of the Granger and Ogden branches of the Oregon Short Line, is a small town in Portneuf Valley, about 2 miles (3.2 kilometers) below its junction with Marsh Valley, in the Snake River drainage basin.

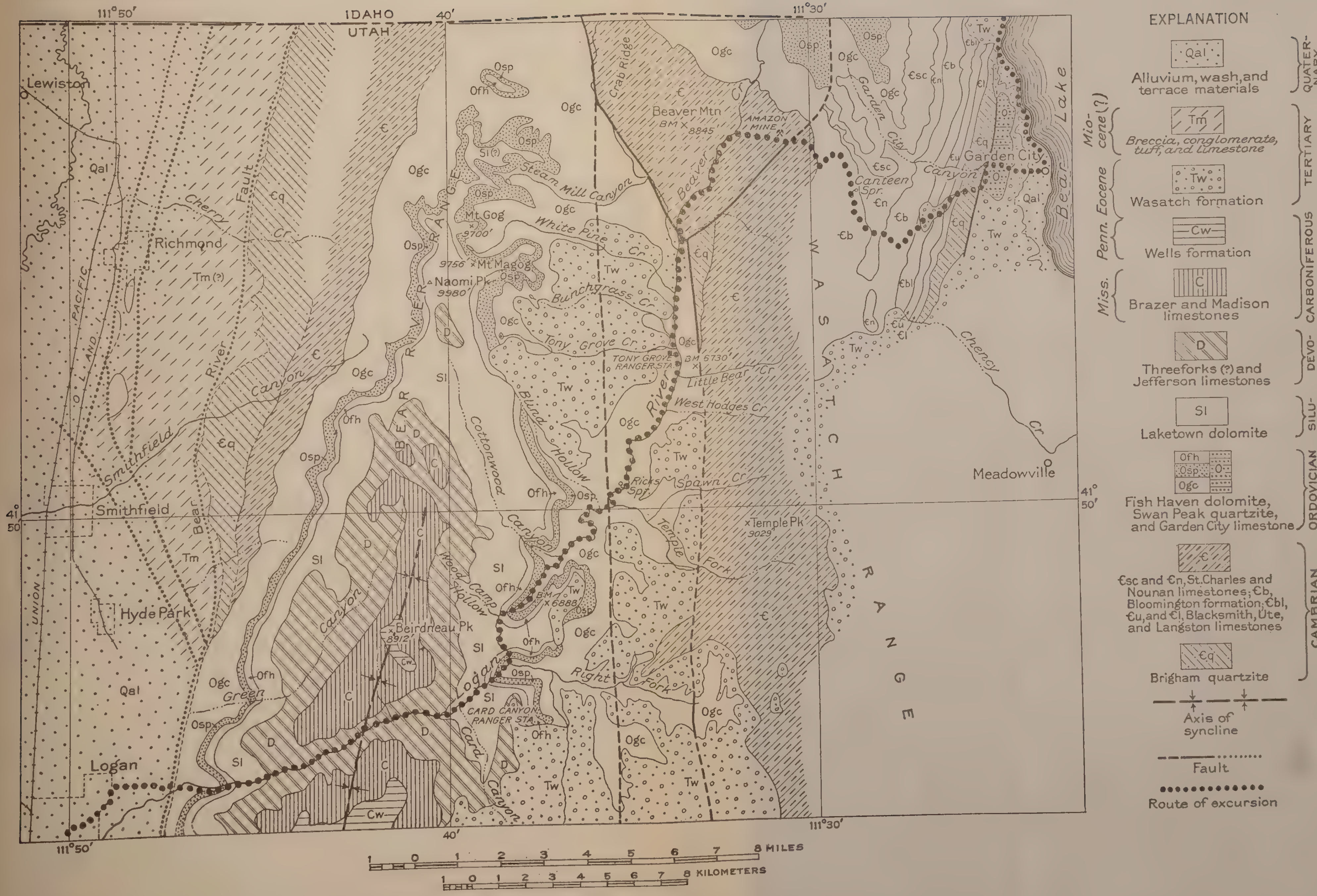
Marsh Valley, originally cut in early Paleozoic formations, was later aggraded with gravel, which in turn was partly eroded away as the country was uplifted. In the new valley thus formed a lava flow was poured out, which descended Marsh and Portneuf Valleys for about 25 miles (40 kilometers), nearly to Pocatello. Somewhat later than the lava flow Marsh Valley and the lower Portneuf were occupied by the outlet of Lake Bonneville, which overspread the lava and carved valleys on each side of it. The valley on the west side is now occupied by Marsh Creek, and that on the east side by the Portneuf River. Marsh Creek now joins the Portneuf at Inkom, about 11 miles (18 kilometers) below McCammon.

A gravel pit near the first milepost east of McCammon on the Granger division of the Oregon Short Line has yielded bone fragments identified by J. W. Gidley as representing three extinct species of mammals—a horse (*Equus* sp.), the mammoth (*?Elephas*, now *Parelephas columbi* according to Osborn), and the bison (*Bison* cf. *B. alleni*), all of Pleistocene age.

The carving of Marsh and Portneuf Valleys was a relatively late event in the erosional history of the region but was accomplished in pre-Wisconsin time, for Lake Bonneville is ascribed to the Wisconsin and probably an earlier stage of the Pleistocene.

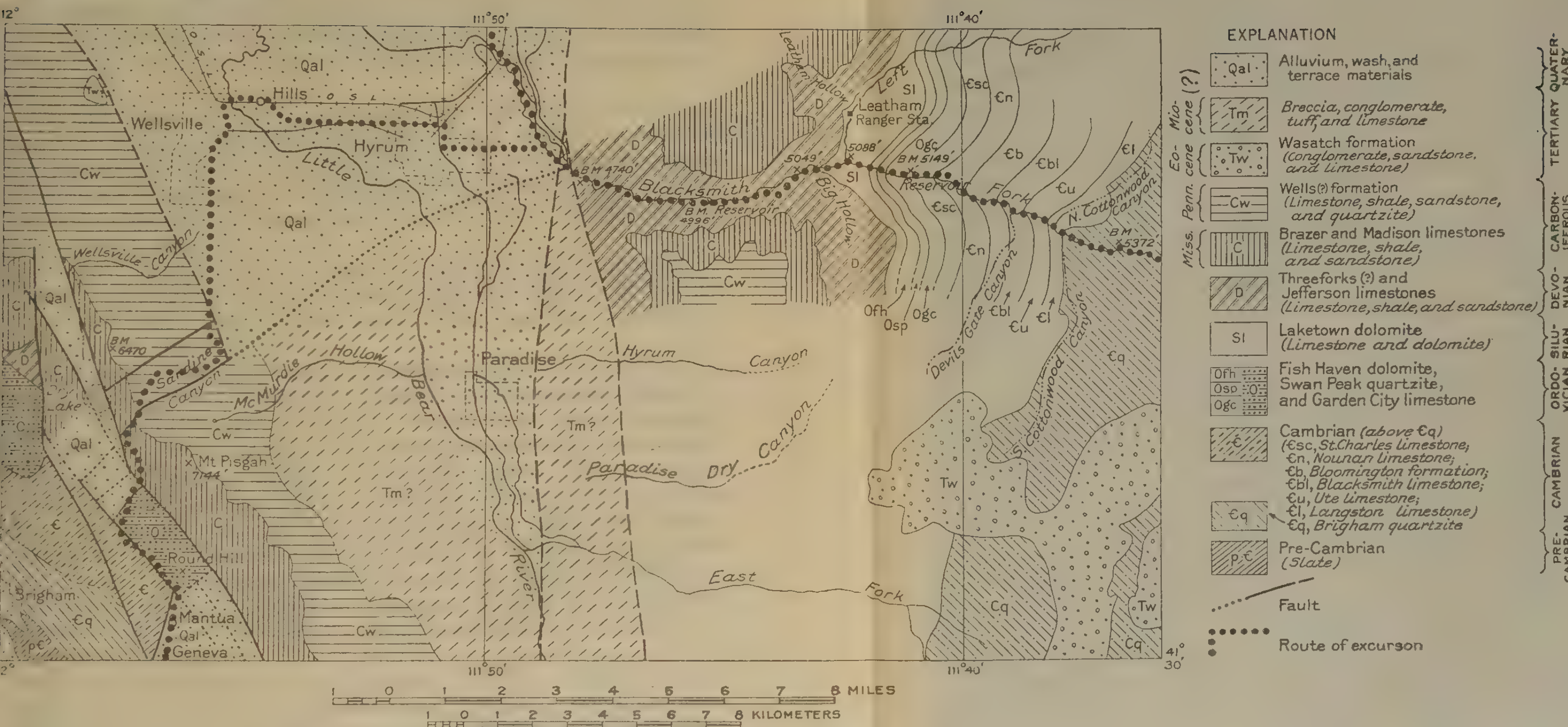
Eastward from McCammon to Montpelier the route follows the Oregon Trail, famous in pioneering days as the principal emigrant route to the Pacific Northwest. Now it is a State highway and is paralleled by a transcontinental railroad. From McCammon to a point just south of Pebble, a distance of about 20 miles (32 kilometers), the route follows the canyon of the

[20] Numbers in brackets refer to Plate 15.



GEOLOGIC MAP OF PART OF LOGAN CANYON AREA

Modified from unpublished maps by G. B. Richardson (east of 111° 30′) and Reed W. Bailey (west of 111° 30′).



GEOLOGIC MAP OF BLACKSMITH FORK AND WELLSVILLE AREAS

Modified from unpublished map by Reed W. Bailey.

Portneuf River. The rocks are chiefly of Ordovician or closely related formations, which are folded and faulted, the structure striking generally northward or northwestward. The broader portions of the canyon are bordered by gentle slopes or benches underlain by Tertiary beds, largely gravel, assigned tentatively to the Salt Lake formation, of Pliocene (?) age. Basalt also is exposed here and there in the canyon, and deposits of travertine form ledges or dams at some places along the river.

At Lava Hot Springs, about 12 miles (19 kilometers) east of McCammon, the State has built a public natatorium. Several hot springs issue from the bank of the river, and in the canyon at and above the hot springs there are considerable deposits of travertine.

On the south side of the canyon, about 500 feet (152 meters) above the creek, there is a manganese mine, which up to 1930 had produced a total of about 3,000 tons of ore averaging about 38 per cent of manganese. The manganese oxide here is believed to have replaced siliceous limestone through the agency of hot-spring waters.

[53] At Pebble lower Paleozoic limestone (presumably St. Charles or Garden City) rated as "high calcium" was burned prior to 1920. Small quantities of this limestone have since been sold to sugar factories.

Beyond Pebble the canyon expands into Portneuf Valley, the northwest continuation of a broad intermontane valley 30 miles (48 kilometers) or more in length from north to south and with a maximum width of about 10 miles (16 kilometers). This great valley is largely occupied by basalt flows, some of which have entered from the east through Tenmile Pass and the Bear River gap, and others have doubtless originated in the valley itself in association with craters that are scattered here and there. The valley is drained in part by the Portneuf River and in part by the Bear River. Large areas of it are sufficiently covered by soil to support dry farms and, where water is available, irrigated crops.

At the west entrance to Portneuf Valley the rocks in the walls near the road on both sides are Ordovician, but Cambrian beds come in farther north. On the east side of the valley the Soda Springs Hills and the Chesterfield Range, which practically constitute northward extensions of the Bear River Range, contain Carboniferous as well as lower Paleozoic rocks and are in part overspread with Pliocene (?) beds assigned to the Salt Lake formation.

Bancroft, in Portneuf Valley, is an agricultural center. The road continues southeastward 11 miles (18 kilometers) to

Alexander, which lies at the entrance to the Bear River gap. As Alexander is approached the basalt flows become more noticeable, and a group of basaltic tuff cones may be observed on the south side of the road.

The Bear River gap separates the Soda Spring Hills on the north from the Bear River Range on the south. This gap is believed to have been formed by the superposition of the Bear River through a Tertiary cover on Paleozoic rocks in an earlier erosion cycle. The basalt that afterward flowed through the gap from the east crowded the Bear River against its south side, producing a steep ledge known as Sheep Rock, which constitutes the north tip of the Bear River Range. Immediately east of the gap the Bear River has been dammed to form a reservoir, used both for power and water storage.

[54] As the town of Soda Springs is approached travertine deposits here and there give evidence of former more extensive spring activity. The so-called "beer springs" of the early explorers were springs of natural carbonated water located in and near what is now the town of Soda Springs. A number of spring mounds can be seen.

The road to Conda (see pl. 14), goes north on the east side of the town. Exposures of basalt may be seen along it, exhibiting characteristic sinks and linear depressions as well as low-lying cliffs.

About 2½ miles (4 kilometers) from Soda Springs, on the east side of the road, a broad white exposure of travertine marks the deposit of Formation Spring, which in relatively recent time built a series of terraces comparable to some of those in the Yellowstone Park.

Threemile Hill, on the west side of the road, is capped by what is probably an erosion remnant of the upper block of the Bannock overthrust (see p. 128) and is itself part of the lower block exposed through a window in the thrust plane. The rocks are Lower Triassic. The Aspen Range, to the east, is composed of Carboniferous and Triassic rocks and includes rich phosphate beds. Conda, lies at the north end of a low ridge that projects northwestward from the Aspen Range.

[55] From Soda Springs to Montpelier the road lies in the Bear River and Bear Lake Valleys. On the west is the Bear River Range, with Sherman (Soda) Peak (altitude 9,669 feet, or 2,947 meters), as the highest and most conspicuous summit in the northern part. On the east side lie the Aspen and Preuss ranges, which include the richest known part of the western phosphate field. The road in part passes through the great window in the Bannock overthrust described on page 128. Beyond Soda Springs the road crosses considerable areas of basalt and travertine. Five

or six miles (8 to 9.6 kilometers) northwest of Georgetown it crosses hills of Pliocene (?) beds (Salt Lake formation) with which are associated a number of travertine hills. Thence it descends on Quaternary alluvial fans to Georgetown, from which the side trip to Georgetown Canyon and the Bannock overthrust is taken. Meade Peak (altitude 9,953 feet, or 3,034 meters) on the south side of Georgetown Canyon is the highest summit in the Preuss Range. The rocks of the Preuss Range southeast of Georgetown are chiefly Jurassic and Triassic, but between Bennington and Montpelier a segment of the upper block of the Bannock overthrust laps up on the west side of the range (p. 129).

About 2 miles (3.2 kilometers) north of Montpelier a recent fault trough which affects Tertiary and Quaternary beds appears as a rather straight dark line at the base of the mountain east of the road. The hills west of the valley in this section are Tertiary (Salt Lake formation).

Montpelier is chiefly an agricultural center. About 3 miles (4.8 kilometers) up Montpelier Canyon there are two phosphate mines owned by the San Francisco Chemical Co.

MONTPELIER TO SALT LAKE

[56] The route from Montpelier runs westward across the Bear Lake Valley to Ovid and thence southward along the west side of the valley. The Bear River Range lies on the west, and the trace of the Bannock overthrust runs along the foothills, gradually approaching the road until at Fish Haven the westernmost branch passes beneath the lake. The road south from Ovid follows approximately a former shore line of Bear Lake, and the towns occupy low-lying former deltas.

The phosphate mines in Paris and Slight Canyons have been shut down for some time, but in 1931 a mine supplying phosphate for the Consolidated Mining & Smelting Co., of Trail, British Columbia, was in operation. About a mile (1.6 kilometers) south of the Utah State line a fine exposure of Brigham quartzite appears on the west side of the road forming a fine easterly dip slope.

[57] At Garden City the road turns west and climbs the Bear River Range. The first ridge with fine exposures along the road is composed of Garden City limestone (Ordovician), the basal formation of Richardson's Ordovician section. (See pl. 18.) Next comes in fault relation the Brigham quartzite, the lowest formation of Walcott's Cambrian section. The intervening fault is believed to be a branch of the Bannock overthrust. From this hill fine views may be had eastward of the Bear Lake Plateau, with its faulted western face, and of Bear Lake itself.

The formations above the Brigham are largely concealed by Tertiary beds until the Bloomington formation is reached. From this point on exposures are fairly good as far as the Logan River.

The rocks at and just east of the divide belong to the Nounan limestone, the uppermost unit of Walcott's Middle Cambrian sequence, but west of the divide the road runs for 3 miles (4.8 kilometers) or more in the limestones and shales of the Bloomington formation. By looking back the section can be seen on the ridge—the St. Charles (Upper Cambrian) with massive ledges and the Garden City not so well exposed. The Swan Peak quartzite occupies the hill at the north.

The Cambrian limestones exposed in Beaver Creek have not been differentiated. A fault zone is passed at the Amazon mine. The shaly beds along the lower part of Beaver Canyon suggest the Ute limestone. The junction area of Beaver Creek and the Logan River is covered by bouldery wash perhaps weathered from Tertiary beds. This persists for 6 or 7 miles (9.6 to 11.3 kilometers) downstream. A fault partly within the Cambrian passes southward half a mile (0.8 kilometer) or more east of the road.

The road continues in Garden City limestone to the vicinity of Wood Camp Hollow, the Swan Peak quartzite descending gradually and finally crossing the stream in a long, low V. The Swan Peak is thinner and darker colored here than in the Montpelier quadrangle and less of a ridge maker.

The Fish Haven and Laketown dolomites form similar pinnacled ledges, but the Fish Haven is thinner and darker colored, more purplish than the Laketown. The road passes through the Laketown for about a mile and then recrosses the Fish Haven, Swan Peak, and Garden City in direct and reverse order in a large bend.

Just below the junction with the Right Fork a large block of Swan Peak quartzite by the roadside affords an opportunity to see the lithology of the rock and displays a remarkable assemblage of casts of fucoids (?).

After another mile stretch of Laketown, the road goes through basal Jefferson limestone (Middle Devonian) for about 5 miles (8 kilometers) and crosses a wide syncline. The Devonian is recognized by slopes and ledges above the pinnacled Laketown.

The Madison limestone (lower Mississippian) can now be seen on the side hills above the Devonian in a nearly vertical ledge that forms a wide gray band on the canyon walls. A subordinate ledge a short distance down the slope below marks the contact with the Devonian. In the center of the syncline the lower slopes are Devonian and the upper slopes Mississippian. Pennsylvanian beds come in farther back on the tops.

On the west side of the syncline the formations successively ise on the canyon sides, with the Garden City probably the vesternmost exposed. Just below the power plant, however, the Garden City is overturned eastward against what appears to be reverse fault. The beds on the west are badly broken but are elieved to be Garden City.

[58] Lake Bonneville terraces extend back up the canyon past he narrows. The road out of the canyon rises northward onto he Provo delta, from the front of which several lower deltas, all elated to Lake Bonneville, can be seen. Cuts on the south face of the terrace reveal its structure, and views across to the south ide of the river show a descending succession of terraces. The Provo shore line is the most strongly marked of all the strands of Lake Bonneville. The Utah State Agricultural College at Logan s located upon it. The Mormon temple at Logan occupies one of the lower terraces. This and the college overlook the broad Cache Valley, which at one time formed a great bay tributary o Lake Bonneville.

[59] The route passes south through Logan to Blacksmith Fork, east of Hyrum, and up the canyon for about 10 miles (16 kilometers). (See pls. 18, 19.) At the mouth of the canyon the edges on the south side are of Madison age, with the phosphate zone of the lower Brazer (upper Mississippian) in the saddle to he east. These beds are downfaulted against the Devonian, which lies on the east. The beds on the north side of the canyon re also faulted and broken. They may be Silurian, but Devonian egins after the first short broken stretch and continues up the canyon for nearly 5 miles (8 kilometers), to the Left Fork. Big gray ledges of Madison limestone can be seen on the upper slopes nd Brazer limestone at the top after the first mile or so of the anyon is passed. The little ledge below the big Madison ledge narks the contact of Devonian and Carboniferous here, as in Logan Canyon.

The Devonian contains a sandstone bed about 20 feet (6 neters) thick which comes down to the tunnel traversed by the oad at the lower dam. There is also a rather massive ledge-orming limestone about the middle of the formation. At the ase of the Devonian is a light-gray sandstone or sandy limestone hat contains fish remains (*Dinichthys?* and others), and perhaps 0 feet (15 meters) above this stratigraphically there is a similar ed weathered reddish and somewhat porous.

The Devonian-Silurian contact lies on the rocky point between he main creek and the Left Fork, on the northwest side. Both he fish-bearing Devonian beds and the coral-bearing Silurian re well exposed there. On the south side of the main creek is a ne westerly dip slope of the Silurian. The view up the Left

Fork shows a succession of Devonian and Carboniferous beds on the west side and of Silurian beds on the east.

About half a mile (0.8 kilometer) above the junction with the Left Fork the creek begins to cross successively the Ordovician and Cambrian formations in descending order. (See pp. 130–138.) The dark ledge of Fish Haven dolomite, not much over 100 feet (30 meters) thick, is succeeded eastward by a light-colored slope occupied by fragments of Swan Peak quartzite. The Garden City limestone, with lighter-colored ledges and slopes, is succeeded just below the second dam and reservoir by dark massive ledges of the St. Charles formation, which begins on a low point on the east side of a small side canyon just east of the big ledges. A white dolomitic bed that in the Montpelier quadrangle comes at the top of the Nounan and float of the Worm Creek quartzite member of the St. Charles were found on the slope of the north side of the canyon opposite the upper part of the reservoir. The big massive ledges of the St. Charles (Upper Cambrian) rise close to the dam and are thus easily recognizable.

The Ute, Langston, and Brigham formations of the Middle Cambrian are readily recognizable and identifiable lithologically; the other formations of this sequence are not so easily distinguished. The westerly dips flatten considerably eastward, and much of the southeastern part of the Logan quadrangle is occupied by Brigham quartzite.

From the Blacksmith Fork Canyon the route passes westward through Hyrum and Wellsville, in the southern part of the agriculturally important Cache Valley, and southward along the State highway to Salt Lake City.

[60] From Wellsville southward additional shore features related to Lake Bonneville can be seen along the base of the mountains.

Beyond Cache Valley the road goes through a Pennsylvanian sequence in turning southwestward through Sardine Canyon. The rocks are in part stained red and badly broken. Turning southeastward the road first traverses Carboniferous rocks, including fossiliferous Mississippian beds, and then enters a considerably faulted area with low hills composed of Ordovician and Silurian rocks. Cambrian beds occupy the higher hills to the southwest. After passing Mantua Valley the road turns westward through Brigham Canyon and crosses successively the Brigham quartzite at its type locality and dark pre-Cambrian (Algonkian) schists.

[61] At Brigham City the Wasatch escarpment is strikingly displayed. The Bonneville shore lines are well shown at the mouth of Brigham Canyon and Squaw Canyon, next north. At

its highest stage Brigham Canyon and Mantua Valley, to the east, were flooded by Lake Bonneville.

[62] The Archean and the succeeding Cambrian sequence may be well seen from the road near Willard, 7 miles (11 kilometers) south of Brigham. The lower dark band is Archean gneiss, the light-colored band is Brigham quartzite, and the next overlying dark band is composed of Cambrian shales and limestones. The Willard overthrust (106, 107) is too far back from the road to be seen clearly. The Wasatch fault, which produced the escarpment, is considered normal and lies near its base, concealed by fans and alluvium.

At Hot Springs the Archean is overthrust westward upon the Cambrian and the Cambrian is repeated by a minor thrust, so that the quartzite is exposed by the road.

[63] Ogden, the second largest city in Utah and an important railroad and agricultural center, lies at the mouth of Ogden Canyon. The geology, as shown by Figure 7, is complex, and the structural features can not be distinguished from the highway, but the general sequence of Archean and Cambrian observed at Willard can be seen.

Ogden Canyon, like Brigham Canyon, was flooded by Lake Bonneville. The Ogden and Weber Rivers and some others built deltas in Lake Bonneville. Some of these deltas have been cut by post-Bonneville faults near the base of the range so that scarps, called by Gilbert (108) piedmont scarps, have been produced in them here and there. Three of these may be seen near the city reservoir at the mouth of Ogden Canyon.

From Ogden to Salt Lake City the road lies some distance out from the mountain front for much of the way, but near Farmington it approaches the mountain base and continues southward fairly near that line. This section of the highway has in recent years been seriously damaged by floods produced by cloudbursts. The effects of some of these are still to be seen. Those near Farmington and Centerville are especially noteworthy.

Note.—For a more detailed description of the route between Ogden and Salt Lake City see pp. 66–68.

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Excursion 9.—THE DINOSAUR QUARRY OF EASTERN UTAH

By Frederick J. Pack

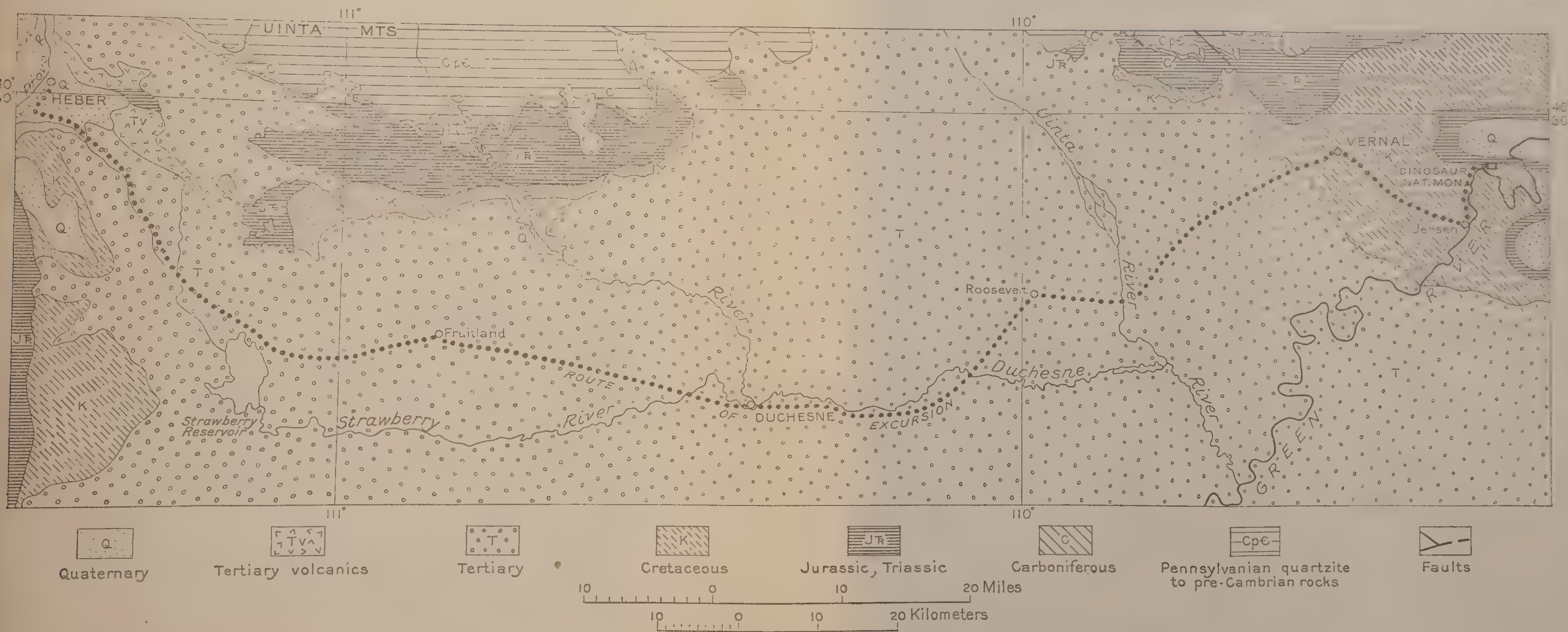
The Dinosaur National Monument (pl. 20) is situated in eastern Utah, 210 miles (338 kilometers) from Salt Lake City. It is reached over highway 40, which is in excellent condition through the entire distance.

ITINERARY

After leaving Salt Lake City, the highway enters Parley Canyon, at the mouth of which Jurassic sandstone, forming the south limb of a steep syncline, occurs on both sides of the road. The highway follows the strike of these formations for about 2 miles (3.2 kilometers) and then enters shales of the same age. At the head of the canyon is a small flow of trachyte, beyond which the road enters Parleys Park. This is a singular erosional depression, which provides headwater for East Canyon and Silver Creek, both tributary to the Weber River.

The route passes within 1 mile (1.6 kilometers) of the Park City mining district. Three miles (4.8 kilometers) east of Park City the highway passes over an extrusive trachyte flow into the Provo River drainage basin.

Beyond Heber City the route leads through Daniels Canyon, at the mouth of which Paleozoic rocks are exposed. In its upper stretches Mesozoic and Tertiary formations are present. At the head of Daniels Canyon the highway leads into the Duchesne River drainage basin, which is tributary to the Colorado River. In Strawberry Valley, a short distance beyond the divide at Daniels Canyon, a reservoir has been constructed, which, by means of a 4-mile (6.4 kilometer) tunnel, furnishes water to the farm lands near Utah Lake, within the Great Basin. Beyond Strawberry Lake for most of the remaining distance, the



GEOLOGIC MAP OF REGION ALONG ROUTE TO DINOSAUR NATIONAL MONUMENT

From Geologic map of the United States, compiled by G. W. Stose.

highway leads through formations of Tertiary age, principally of continental origin.

Ashley Valley, in which the city of Vernal is situated, is structurally a broad anticline, the axis of which is generally parallel with the surface drainage. Natural gas has been discovered on this anticline. Some 15 miles (24 kilometers) beyond Vernal is the village of Jensen, which marks the site where Padre Escalante, the first white man to visit Utah, crossed the Green River in 1776. Half a mile (0.8 kilometer) west of Jensen the highway leads directly north for 6 miles (9.6 kilometers) to the Dinosaur National Monument.

UINTA MOUNTAINS

The Dinosaur National Monument is situated on the south flank of the Uinta Mountains, the principal east-west mountain range in North America. This range forms a vast anticline, broken by a fault on the north side which strikes parallel with the mountain axis. On the south flank the beds have a general dip close to 40°; at the north the dip is somewhat steeper.

Near the center of the Uinta uplift massive quartzites of Cambrian or pre-Cambrian age are exposed. These are flanked by formations of later origin up to and including the Cretaceous.

The major part of the flexing of this range occurred simultaneously with the appearance of the Rocky Mountains, near the end of the Mesozoic era. Tertiary formations were then laid down, chiefly as continental deposits, near the flanks of the range. The region was affected by a second uplift near the middle of the Tertiary, which resulted locally in a further flexing of the older formations, together with a slight bending of the later ones. Thus, the Tertiary rests unconformably upon the older rocks.

At the Dinosaur National Monument more resistant formations make great hogbacks, cut by several canyons trending north and south. The highway leading to the dinosaur quarry enters one of these small canyons. At the mouth of the canyon is the Ferron sandstone, a local member within the Cretaceous. Immediately beyond and below the Ferron is the lower Mancos shale, at the base of which lies the Dakota (?) sandstone. Below the Dakota (?) is the Morrison formation, which carries the dinosaur remains.

The rocks at the quarry dip roughly 50° S. The chief fossil-bearing member is a coarse-grained sandstone, evidently of fluviatile origin, about 4 to 8 feet (1.2 to 2.4 meters) in thickness. It is bounded above and below by shales and shaly sandstones.

PALEOGEOGRAPHY

The dinosaurs lived in the lowlands of the Rocky Mountain geosyncline in late Comanchean time. Their habitat was principally within marginal areas close to rivers and fresh-water lakes. Evidence in the quarry and elsewhere leads to the conclusion that at this locality a river crossed the old Comanchean terrane. Furthermore, the evidence warrants the conclusion that occasionally the carcasses of these gigantic creatures floated down with the flood waters and became stranded upon a shallow sand-bar. Most of the long necks and the long tails of these creatures, as exposed in the quarry, point in the same direction. This is interpreted to indicate the direction in which the stream was flowing.

After Comanchean time the country was submerged, and during the Cretaceous alone nearly 2 miles (3.2 kilometers) of sediment was deposited on the dinosaur remains. Still later, at the end of Cretaceous time, the Uinta uplift occurred, followed by a long period of erosion, with deposition of Tertiary sediments along its flanks. Since this second uplift the Uinta Mountains have been denuded to such an extent that the dinosaur burial ground is again at the surface. (See pl. 10, *B*.)

HISTORY

The locality was discovered some 20 years ago by Earl Douglas of the Carnegie Institute of Pittsburgh. The Carnegie Institute operated the quarry for 13 years and removed probably a score of these gigantic creatures, some of which are now mounted in its museum at Pittsburgh.

After the operations of the Carnegie Institute the United States National Museum entered the quarry and removed a skeleton of *Diplodocus*, now on exhibition at Washington.

In 1923–24 parties from the University of Utah entered the quarry under the supervision of the writer and removed the partial remains of four skeletons—a *Brontosaurus*, a *Barasaurus*, a *Stegosaurus*, and an *Allosaurus*. Subsequently the partial skeleton of *Barasaurus* was transferred to the American Museum of Natural History, where it is now on exhibition. The University of Utah transported its material from the quarry to Salt Lake City in 19 heavily loaded wagons.

FUTURE DEVELOPMENT

It is now proposed to build an attractive field museum at the site of the quarry. This will be done by removing rock above the fossil-bearing member and then working the fossils into bas-relief. It is proposed to expose the fossil-bearing member for a distance of about 150 feet (46 meters) laterally and 50 feet (15 meters) vertically. This great inclined stratum, with the fossils exposed within it, will form the north wall of the museum proper. It is proposed to construct a building over the site, properly lighted from above and sufficiently large to display other fossils found in the locality. This project is now being developed under a threefold arrangement between the United States National Park Service, the American Museum of Natural History, and certain interests in Utah. In 1931 the United States Government temporarily withdrew nearly 8,000 acres (3,200 hectares) from the public domain in this vicinity for investigation and classification for an addition to the Dinosaur National Monument.